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OPTICAL ANALYSIS OF AIRCRAFT TRANSPARENCIES (OPTRAN)
VOLUME II: OPTRAN USER'S MANUAL

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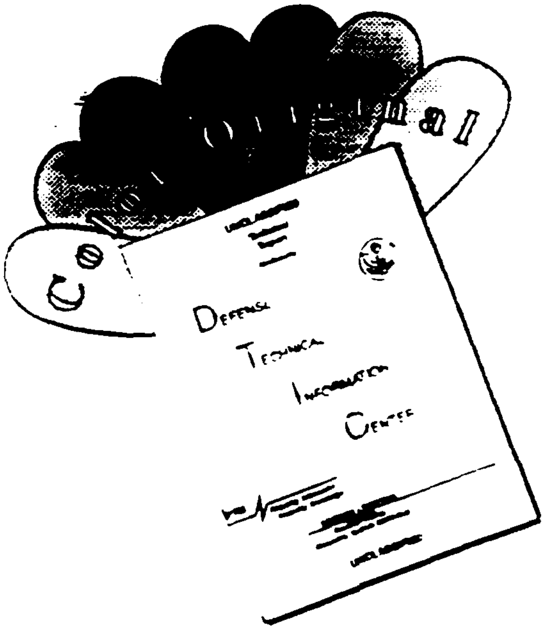

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The operation of the Optical Transmission (OPTRAN) code developed to predict the optical performance of aircraft transparencies is described. The code allows the effects of operational loads to be analyzed. User input is defined and job control procedure examples are provided. The operation of finite element thermal and stress analysis codes with which OPTRAN is interfaced is described and references provided. The operation of several interface codes is also documented. The code accepts input files and generates output files compatible with commercially available finite element pre- and post-processing software.

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FOREWORD

This report was prepared by the University of Dayton Research Institute under Rockwell International P.O. #L9FM-60048-W-439, Project Title "Transparency Optical Analysis Capability Development," under United States Air Force contract F33615-86-C-3414. The project was administered by the Wright Research and Development Center, Wright-Patterson Air Force Base, Ohio. Mr. Richard A. Smith, WRDC/FIVR, was Laboratory Project Engineer.

This is the final report submitted under the University of Dayton's efforts, and documents the software developed in the period from December 1988 to May 1990. Project supervision and technical assistance was provided through the Aerospace Mechanics Division of UDRI, Mr. Dale H. Whitford, Supervisor. Project Manager for this effort was Mr. Blaine S. West, and the Principal Investigator was Mr. John W. Fielman, who was also responsible for code development and code interfaces. Dr. John S. Loomis was the primary contributor of the optics theory and ray trace analysis code. Dr. Robert A. Brockman made strategic modifications to MAGNA and the MAGNA interface codes, without which the effort could not be completed.

This report is published in two volumes. Volume I, OPTRAN Theoretical Manual, describes the mathematical theory and working equations upon which the OPTRAN code is based. OPTRAN was developed to predict the optical performance of current and future canopy designs. Orthotropic optical effects are computed as a function of temperatures and stresses predicted by finite element codes. Volume II, OPTRAN User's Manual, describes the operation of OPTRAN and the finite element codes with which OPTRAN is interfaced. The operation of pre- and post-processor software is also described.

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SECTION 1

INTRODUCTION

This user's manual describes the operation of a system of codes which predicts the optical quality of transparent components. The optical transparency analysis code (OPTRAN) was developed to predict optical distortion introduced by thermally distorted, mechanically loaded air crew enclosure transparencies.

OPTRAN is integrated with thermal analysis (STAPAT) and stress analysis (MAGNA) codes which compute the transparency temperature gradient, stress field, and deformed geometry. The commercially available PATRAN Plus finite element geometric modeling pre- and post-processing software system is used as an interface between the analysis codes. Translation utilities which permit the exchange of data between the analysis codes and PATRAN Plus are also part of the system of codes.

The name of each translation utility indicates the direction of translation. PATSTA translates PATRAN model data into STAPAT input data format. STARAN translates the output of the STAPAT to a format suitable for input to PATRAN. PATMAG translates PATRAN modeling data into MAGNA input format. MAGPAT translates MAGNA results to the format required for input to PATRAN, and MAGOPT translates MAGNA results for input to either OPTRAN or PATRAN. OPTRAN was written to input PATRAN modeling data without translation, and OPTRAN results are written in PATRAN results compatible format, eliminating the need for additional translators.

OPTRAN was developed by the University of Dayton Research institute under sponsorship provided by Flight Dynamics Laboratory, Wright Research and Development Center, Wright-Patterson Air Force Base, Ohio. The STAPAT development by Sverdrup Technology, Inc., Tullahoma, Tennessee, was also sponsored by Flight Dynamics Laboratory. MAGNA has been developed by the University of Dayton Research Institute, Dayton, Ohio. PATRAN Plus is a product of PDA Engineering, Costa Mesa, California.

The STARAN and MAGOPT translator utilities were written by the University of Dayton Research Institute as part of the OPTRAN development effort. MAGOPT is a derivative a nodal stress averaging code (STRAVG) written earlier by the University for use with MAGNA. PATMAG and MAGPAT were also written by the University as part of the MAGNA development. PATSTA was developed internally by the Flight Dynamics Laboratory by modification of PATMAG.

OPTRAN, STARAN, and MAGOPT are written in ANSI FORTRAN-77 and are operational on DEC VAX/VMS operating systems. OPTRAN and MAGOPT are also operational on the CRAY/COS system.

Section 2 of this report provides an overview of OPTRAN's functionality. Section 3 provides the user information necessary to execute the entire system of codes with a detailed description of the OPTRAN input data. Input for the other analysis codes is described in the respective manuals which are referenced as necessary in Section 3. Examples are given in Section 4.

SECTION 2
OPTRAN OVERVIEW

OPTRAN is a ray trace code which evaluates the optical quality of aircraft transparencies subjected to operation load conditions. The mathematical theory on which the code is based is presented in the OPTRAN Theoretical Manual (Reference 1).

The deformed geometry is input to OPTRAN as parametric cubic solids referred to in the PATRAN documentation as hyperpatches and referred to in the remainder of this report as Geometric Hyperpatches, to distinguish them from Data Hyperpatches used to map the temperature and stress fields. The mathematical formulation for both types of hyperpatches is presented in detail in Chapter 37 of the PATRAN Plus User's Manual (Reference 3). The hyperpatch formulation is that of a cubic solid (64 node) isoparametric finite element. Coordinates and other data parameters are mapped within the hyperpatch with the same parametric equations.

The OPTRAN code accounts for three dimensional orthotropic optical effects. An orthotropic index of refraction ellipsoid is computed as a function of the stress and temperature values. Orthotropic effects can result from either orthotropic material properties or from birefringence caused by stress optic effects. Orthotropic indices of refraction are computed as a function of the temperature and stress values interpolated within the transparency volume.

Optical material properties include orthotropic indices of refraction, orthotropic temperature coefficients of the indices of refraction, and a six by six matrix of stress optic coefficients. Orthotropic optical material properties input to OPTRAN are defined with respect to optic axes. Optic axis orientation data may optionally be input.

The optic axes are defined with respect to a reference axis. The reference axis can be either the global coordinate axis or axes defined by the derivatives of the global coordinates with respect to the Geometric Hyperpatch parametric variables. This latter reference axis option allows the optic axis orientation to vary with the curvature of the transparency. By default, the optic axes are aligned with the reference axes and by default the global coordinate axes are the reference axes.

For raytracing, the entrance and exit surfaces of each part must be identified. Surfaces must be numbered sequentially from the outside of the aircraft to the eye. The eye position and a set of pilot reference axes must also be defined. Rays are specified by direction angles with respect to the pilot coordinate system. Rays can also be specified indirectly by defining a mesh of nodes over the first entrance surface. The 3D coordinates of these nodes are used to generate ray directions.

The following method is used to find the ray from a known target location that intersects the eye point. First, we aim a ray from the target to the eye and trace an actual ray until the ray intersects the eye plane. Then we trace differential rays (close to the original ray), differing first in azimuth and then in elevation. The intersection of these rays at the eye plane (XY plane in pilot coordinates) is used to generate a first-order matrix that can be solved to give a correction to the original ray, that is, a new ray that now intersects the eye point. Rays are represented as straight lines in space. Rays are refracted at the point they intersect an optical surface. The two operations involved in raytracing, therefore, are finding the intersection of a ray with the surface, and refracting the ray at the surface. For parametric surfaces, ray intersection is an iterative procedure, requiring a two-dimensional nonlinear optimization. Calculating the direction of propagation of the refracted ray is also an iterative process, since the index of refractive varies with direction.

Finding the first intersection on an entrance surface requires a search over available patches. For an intersection point to be valid, the parametric variables corresponding to the intersection point must lie within the bounds of $0<=(u,v,w)<=1$.

Once the entrance hyperpatch face has been identified, the ray may be traced through the part without additional searching because the PATRAN geometry file identifies adjacent hyperpatches. After a ray exits a part, however, another search of a list of patches may be required to find the entrance into the next part.

An extensive list of variables is generated at each intersection point. These include the hyperpatch ID and face number, material ID, hyperpatch parameters (u, v, w), corresponding 3D coordinates (x, y, z), the direction of the surface normal, the direction of the refracted ray, a reference polarization direction, polarization and transmittance arrays, and auxiliary variables needed to generate differential rays. A detailed surface-by-surface list of this information can be generated on the output listing.

There are three output files generated by OPTRAN. The first is the output listing, which contains a copy of the input parameters, detailed ray trace information, error messages, and summary tables. The second is a PATRAN nodal results file, which may be either a RESULTS file with 14 columns of data, or a CHECK file with 18 columns of data, depending on the type of output requested. Section 3.9.2 describes the contents of the RESULTS file, and Section 3.9.4 describes the CHECK file. A PATRAN nodal results file can be used in PATRAN to produce a variety of 3D plots. The third file is an OPTRAN optical results file, which contains outline segments that define the field of view and raytrace information on a uniform grid of azimuth/elevation variables. The OPTRAN optical results file is used in OPTINT to generate two-dimensional grid distortion plots, angular deviation fields, and polarization ellipses.

SECTION 3
CODE OPERATION INSTRUCTIONS

This section describes the steps required to perform a complete thermal, stress, and optical analysis using STAPAT, MAGNA, and OPTRAN, respectively. While STAPAT and MAGNA were not developed as part of the optical analysis code development effort, their operation is described briefly because thermal and stress analyses are required as part of a rigorous optical analysis. The operation of STAPAT and MAGNA are described in detail in their respective manuals (References 2 and 4).

The commercially available PATRAN finite element pre- and post-processing software system provides an interface mechanism between the analysis codes. The use of PATRAN is assumed in conjunction with the operation analysis codes in the following discussions. The flow of data between PATRAN and the analysis codes is indicated in Figures 3.1 and 3.2. The use of PATRAN could potentially facilitate the use of other thermal and stress analysis codes in conjunction with an optical analysis.

It is worth noting that, while convenient, the use of PATRAN is not required for the operation of any of the analysis codes if other methods can be used to generate the necessary input files and analyze the results files. The detailed contents of these files is described fully, either in this report or in the report references.

A working knowledge of PATRAN is assumed in many of the discussions in the remainder of this section. Readers unfamiliar with PATRAN may wish to refer to the PATRAN User's Manual (Reference 3) to understand the use of PATRAN, and for definitions of the PATRAN terms used in this section.

3.1 CODE OPERATION OVERVIEW

The STAPAT code (Reference 2) was developed specifically to perform thermal analyses of aircraft transparencies. The TAP module of STAPAT computes the temperature distribution within the

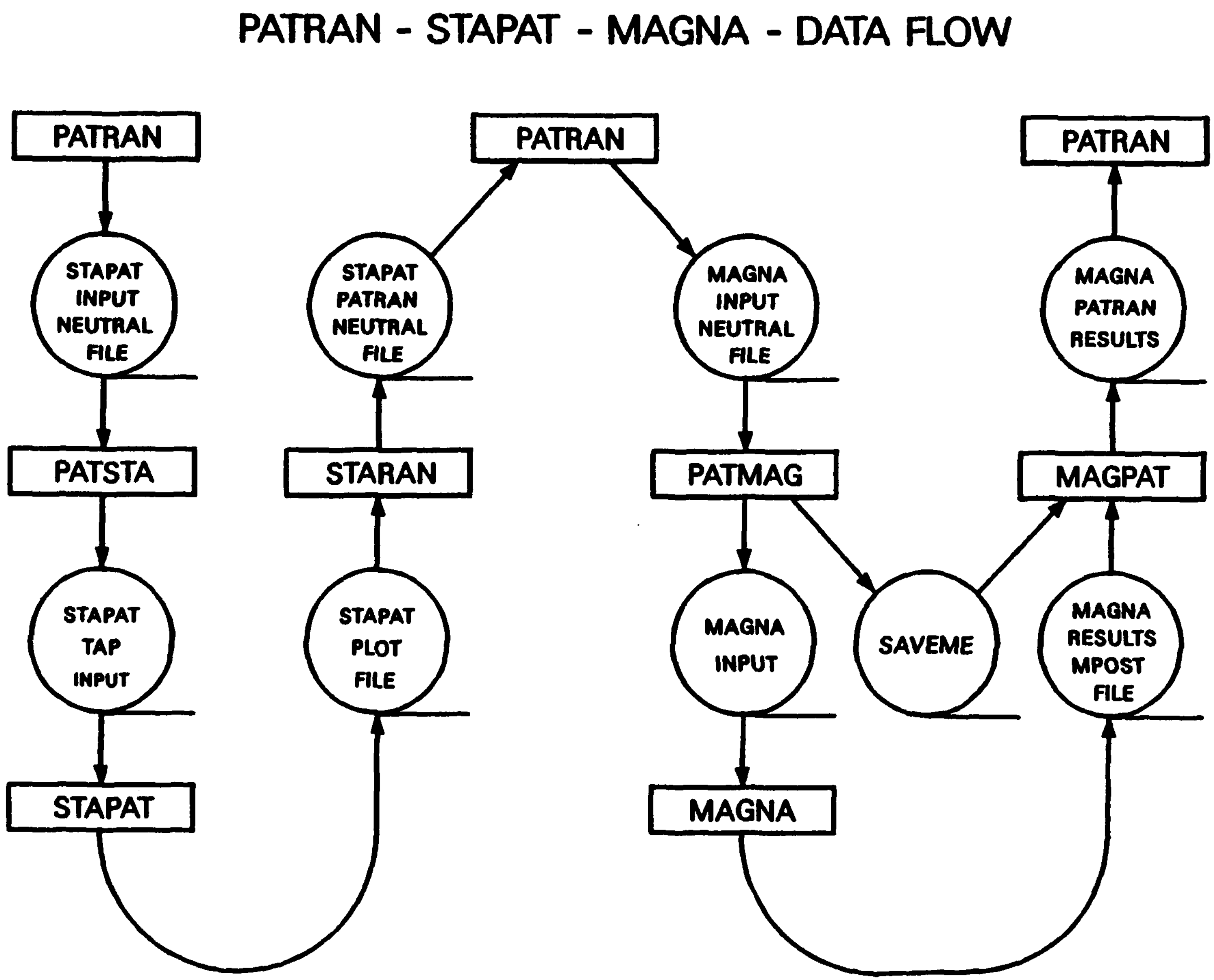

Figure 3.1. PATRAN, STAPAT, and MAGNA Data Files.

MAGOPT - PATRAN - OPTRAN - OPTINT - DATA FLOW

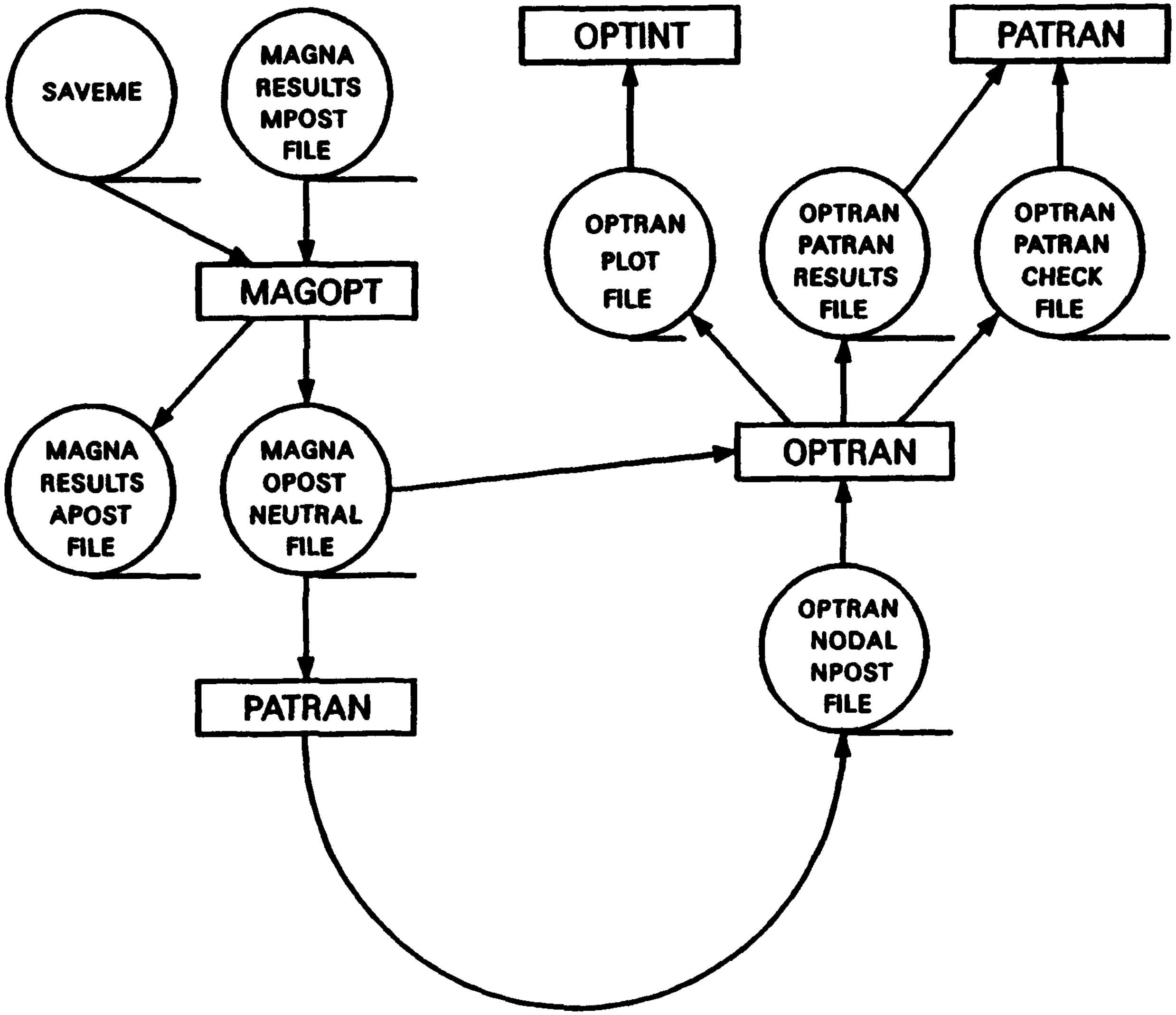

Figure 3.2. MAGOPT, PATRAN, OPTRAN, and OPTINT Data Files.

volume of the aircraft transparency. The STARAN interface code translates STAPAT thermal analysis plot file results into PATRAN Phase 1 neutral file format for input to PATRAN.

The data from the STARAN generated file can be input to PATRAN to define transparency model geometry and temperature distribution from which a MAGNA finite element model can be created. PATMAG translates PATRAN finite element stress analysis models from neutral file format into MAGNA input data format. The MAGPAT code shown in Figure 3.1 translates MAGNA MPOST output files into PATRAN element results file format for evaluation.

The MAGNA MPOST file must also be input to the MAGOPT code shown in Figure 3.2 to input MAGNA results to OPTRAN. MAGOPT translates the MAGNA results into PATRAN Phase 1 neutral file format with the stresses averaged at the nodes for input either to PATRAN or directly into OPTRAN. PATRAN can be used to generate new nodal information to define the input incident light ray locations and blend the deformed geometry. This last step is necessary to use PATRAN to analyze optical analysis results.

The OPTRAN optical analysis code potentially generates three different output data files and a listing file. The first file is formatted for input into the OPTINT optical analysis results graphic display code. The second file which can be generated by OPTRAN is an optical analysis results file in PATRAN nodal results format and provides a means of viewing results through the use of PATRAN. The third file is contains some of the optical analysis internally computed parameters on which the optical analysis was based. This CHECK file was used extensively in the debugging of OPTRAN. It has also proven useful in understanding optical analysis results.

It is not necessary perform thermal and stress analyses in order to perform an optical analysis. OPTRAN requires a model of the transparency geometry in PATRAN hyperpatch format. This can be generated by MAGOPT from the MAGNA MPOST results file or directly using PATRAN. The latter method permits analysis of uniform temperature, unstressed transparencies.

3.2 STARAN DATA TRANSLATION

The STARAN code reads nodal coordinate, element connectivity, and nodal temperatures from the plot file generated by the TAP module of STAPAT. The nodal temperatures are read at the time specified by the user. STARAN translates each of the eight node solid elements output by TAP into PATRAN Geometric Hyperpatches. A corresponding PATRAN Data Hyperpatch describing the temperature within the Geometric Hyperpatch is also generated from temperature data output by TAP. The generated Phase 1 Geometric Hyperpatches and Data Hyperpatches are output by STARAN in PATRAN neutral file format to permit PATRAN to be used to generate a MAGNA stress analysis model independent of the model used by TAP. The PATRAN neutral file format is described in full detail Chapter 29 of Reference 3.

A single user input card is required to specify the time at which the temperature data is to be taken. Only one time can be specified per execution. On a VAX/VMS system, the input card is read from SYS$INPUT and the time is read from columns 1-10 with an E10.0 format. A sample VAX/VMS command file for running STARAN with the single time selection input data card is shown in Table 3.1. The time specified is 6.0 seconds.

TABLE 3.1

STARAN VAX/VMS COMMAND FILE AND INPUT DATA EXAMPLE

```
$ ASSIGN SC3TF4.PLOT STAPLT
$ ASSIGN SC3TF4.SP   SPOST
$ RUN [OPTRAN.STARAN]STARAN.EXE
6.0
$
$ EXIT
```

Where: **SC3TF4.PLOT** is the input Plot File generated to by the TAP module of STAPAT,

SC3TF4.SP is the output PATRAN Neutral file generated by STARAN.

The VAX/VMS version of STARAN (currently the only version) opens two files, the STAPLT input plot file and the output SPOST PATRAN neutral file which STARAN creates. A new SPOST file is created whenever STARAN is executed. If **$ ASSIGN** statements like those shown in Table 3.1 are not executed, STARAN will fail to execute unless a file named **STAPLT.DAT** exists in the default directory. If the above SPOST file assignment is not made, a new file named **SPOST.DAT** is created in the default directory.

PATRAN grid neutral file format data are generated from the STAPAT plot file nodal input data and are written to the SPOST file. The grid point numbers match the TAP module node numbers. The grid numbers are output with the Geometric Hyperpatches to define the Geometric Hyperpatch topology.

The Geometric Hyperpatches generated correspond one to one with the eight-node solid elements read from the STAPAT generated plot file, and are numbered consecutively from 1 to the number of STAPAT elements in the order in which they were read from the input plot file. The output Geometric Hyperpatch numbers do not match the input element numbers unless elements were numbered consecutively starting at one. A Data Hyperpatch with the same number is generated for each Geometric Hyperpatch to map the temperature field.

3.3 MAGNA INPUT DATA PREPARATION

The file generated by STARAN describes the PATRAN Phase 1 geometry and can be used as a basis for generating a MAGNA input model. PATRAN temperature neutral file data packets can be generated using PATRAN DFEG commands. The PATMAG (PATRAN to MAGNA translator) code has been modified as part of the OPTRAN development effort to generate MAGNA nodal temperature input data from the packets. PATMAG was also been modified to accept the MAGNA element type 1 variable 8- to 27-node element. Many of the configurations of the variable node element are supported by recent versions of PATRAN.

The optical analysis code currently supports only the use of solid elements because light rays must be traced volumetrically. All the MAGNA solid elements with the exception of the layered shell element (MAGNA element type 11) are supported by MAGOPT.

Other elements such as trusses and beams commonly used to model transparency support structures may be included in the stress analysis model, but the transparency material to be optically analyzed must be modeled using the solid elements supported by MAGNA and OPTRAN. MAGOPT only writes data for OPTRAN supported elements to the OPOST file. (Note: MAGOPT writes data for all MAGNA element types to the APOST file.)

3.4 MAGNA AND MAGOPT OPERATION

The next step is to run MAGNA as usual. The operation of MAGNA and the nodal stress averaging code (STRAVG) is described in Reference 4. MAGOPT is a derivative of STRAVG and performs the same functions plus generating a PATRAN neutral file (OPOST) for input to either PATRAN or OPTRAN. MAGOPT reads the MAGNA output MPOST file to obtain displacements and stresses. MAGOPT, like STRAVG, averages the stresses at the nodes. The APOST file generated by MAGOPT is identical to that generated by STRAVG. MAGOPT also reads the MAGNA input data file to obtain nodal temperatures which are not available from the MPOST file.

A PATRAN Geometric Hyperpatch is generated for each solid element contained in the MAGNA stress analysis model. Seven Data Hyperpatches are generated for each Geometric Hyperpatch to map temperature and the six orthogonal stress parameters within the Geometric Hyperpatch. Data for nonsolid stress elements such as plates, beams, springs, etc. included in the stress analysis model are output to the APOST results file, but no data are output to the OPOST file for these elements.

3.4.1 <u>OPOST File Geometric and Data Hyperpatch Numbering</u>

The execution of OPTRAN requires that the user define light input and exit surfaces in terms of Geometric Hyperpatch numbers and Geometric Hyperpatch face numbers. If possible, MAGOPT, by default, numbers the Geometric Hyperpatches with the solid element numbers from the MAGNA model.

The use of multiple solid element types can cause Hyperpatch number confusion. MAGNA elements are numbered by type by number with the result that multiple solid elements with the same element number (but different type) can and in fact are likely to exist within the same model. MAGOPT checks for this situation by comparing each new Geometric Hyperpatch number with a list of those numbers previously assigned. If the new Hyperpatch number has been used, a number one higher than the maximum previous number is assigned instead. This method of Geometric Hyperpatch numbering permits the use of the original element numbers in models with multiple materials using only a single element type, but has unpredictable results when multiple solid element types are present within a model.

The OPTRAN user has two methods of resolving the Geometric Hyperpatch numbering problems which can result from the use of multiple solid element types. He can input the model to PATRAN from the OPOST file and graphically examine the numbers assigned by MAGOPT, or he can force the original PATRAN element numbers to be assigned to the Geometric Hyperpatches using data read from the SAVEME file generated when PATMAG was executed.

PATRAN requires unique element numbers. PATMAG renumbers elements to accommodate the MAGNA convention of numbering elements by type, but writes element equivalence data to the SAVEME file. This was done to permit MAGPAT to reassign the original element numbers so that the element results can be input to PATRAN for analysis. MAGOPT is capable of taking advantage of this information. As a user option, the element number equivalence data from the SAVEME file can be input to MAGOPT and used to assign the original PATRAN element numbers to the Geometric and Data Hyperpatches generated by MAGOPT. The use of this option has no effect on the APOST file contents generated by MAGOPT, which retains the MAGNA part and element numbering.

Data Hyperpatches are numbered with respect to the Geometric Hyperpatch number **regardless** of how the Geometric Hyperpatch numbers are assigned. The inclusion of one or more nonsolid elements types in the stress analysis model does not create a problem, because no Geometric or Data Hyperpatches are generated and no information is output to the OPOST file for these elements.

Like the STRAVG code (See Section 5.7 of Reference 4) from which it is derived, MAGOPT does not require user input data. However, input can be supplied to control the amount of printed output, increment numbers to be processed, and whether or not the SAVEME file data are to be used to control Hyperpatch numbering. When input is supplied to MAGOPT, the first input line must contain a printing specification and may optionally invoke the use of the SAVEME file. The first input line must be one of the following:

```
            PRINT=YES
or          PRINT=NO
or          PRINT=YES SAVEME
or          PRINT=NO  SAVEME
```

beginning in column 1, with no embedded blanks in the print and SAVEME file control statement. The SAVEME keyword must begin in column 11 with no embedded blanks. Additional input lines should contain numbers or ranges of increments to be processed by MAGOPT; increment ranges are distinguished by a negative sign on the second number of a pair. The increment number data are read in 16I5 format, on as many lines as necessary, with blank fields ignored.

The following example of MAGOPT input requests minimal printing, the processing of increments 5, 7, and 10 through 14, and invokes the use of the SAVEME file.

```
PRINT=NO  SAVEME
    5    7
   10  -14
```

Requested increments which do not appear on the input MPOST file are simply ignored. For example, if the MPOST file contained increments 6 through 12, the above input stream would cause increments 7, 10, 11, and 12 to be processed and written to the APOST and OPOST files.

3.4.2 MAGNA and MAGOPT CRAY/COS Job File Example

A sample CRAY/COS operating system execution control file is shown in Table 3.2. There are three execution steps specified along with fetching and disposing of the necessary data, listing, and source code files. All files with the exception of the MAGNA executable are fetched from or disposed to the VAX/VMS front end processor. The front end processor file names can be chosen by the user, but they must be assigned to the FORTRAN Unit numbers indicated in the example (A=FTnn.). The JCL parameters which can vary with each execution are underlined in bold. Dummy passwords (xxxxxxx) are used for the obvious reason.

TABLE 3.2

CANOPY SAMPLE CRAY (COS) JOB FILE

```
JOB,JN=CANOPY,CL=P2,T=150,US=P890028,MFL.
ACCOUNT,AC=P890028,APW=xxxxxxx,UPW=xxxxxxx.
*. CRAY JOB SUBMISSION
*. MAGNA FINITE ELEMENT ANALYSIS
*. MAGOPT STRESS AVERAGING AND DATA CONVERSION
REWIND,DN=$OUT.
FETCH,DN=MAGDAT,SDN=MAGDAT,TEXT=^
'[P890028.PLATE]CANOPY.MAGDAT'.
ASSIGN,DN=MAGDAT,A=FT05.
ASSIGN,DN=MPOST ,A=FT90.
ASSIGN,DN=STIFF ,A=FT12.
ACCESS,DN=MAGNA,PDN=MAGNAEXE,OWN=D840200.
MAGNA.
DISPOSE,DN=$OUT,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]CANOPY.OT'.
RELEASE,DN=FT10:FT12:FT14:FT20:FT98.
FETCH,DN=MOPT,SDN=MAGOPT,TEXT=^
'[P890028.PLATE]MAGOPT.CRY'.
CFT,I=MOPT,L=MOLIS.
DISPOSE,DN=MOLIS,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]MAGOPT.LIS'.
RELEASE,DN=MOPT.
REWIND,DN=MPOST.
REWIND,DN=MAGDAT.
ASSIGN,DN=MAGDAT,A=FT61.
ASSIGN,DN=OPOST,A=FT62.
ASSIGN,DN=MPOST,A=FT90.
ASSIGN,DN=APOST,A=FT98.
FETCH,DN=MOPTIN,SDN=MOPTI,TEXT=^
'[P890028.PLATE]MAGOPT.INP'.
FETCH,DN=SAVEME,SDN=SAVE,TEXT=^
'[P890028.PLATE]SAVEME.DAT'.
ASSIGN,DN=SAVEME,A=FT63.
ASSIGN,DN=MOPTIN,A=FT05.
ASSIGN,DN=MOPTOT,A=FT06.
LDR.
DISPOSE,DN=MPOST,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]CANOPY.MP'.
DISPOSE,DN=OPOST,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]CANOPY.COP'.
DISPOSE,DN=APOST,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]CANOPY.CAP'.
DISPOSE,DN=MOPTOT,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]MAGOPT_CANOPY.LIS'.
```

The contents of the files fetched from and disposed to the VAX/VMS front end processor shown in Table 3.2 are described in Table 3.3.

TABLE 3.3

CANOPY EXAMPLE FILE DESCRIPTIONS

FILE	DESCRIPTION
CANOPY.MAGDAT	MAGNA input data described in detail in Section 8 of Reference 4
CANOPY.OT	MAGNA results output listing file.
MAGOPT.CRY	The CRAY version of MAGOPT FORTRAN Source Code
MAGOPT.LIS	MAGOPT Compilation listing generated by the CRAY/COS CFT FORTRAN compiler
MAGOPT.INP	MAGOPT input data file which controls the MAGOPT print option, use of the SAVEME file, and increment selection
SAVEME.DAT	File Generated by PATMAG containing nodal and element number equivalence data.
CANOPY.MP	MAGNA results summary data MPOST file described in Section 5.7 of Reference 4
CANOPY.COP	OPOST file generated by MAGOPT for input to OPTRAN described in Section 3.5 of this report
CANOPY.CAP	Nodal averaged MAGNA results APOST file described in Section 5.7 of Reference 4
MAGOPT_CANOPY.LIS	MAGOPT execution output listing file

The PATRAN Packet 34 Geometric Hyperpatches generated by MAGOPT define the model deformed geometry. Displacements are added to the nodal coordinates before the solid finite element shape functions are used to compute the rectangular global coordinates of the 64 PATRAN Grid points from which Geometric Hyperpatches coefficients are computed. The 64 points are located on a 4x4x4 mesh of equally spaced points in the 3D solid finite element isoparametric shape function space. The location of the 64 points global rectangular coordinate space is a function of the element shape.

Temperature and six orthogonal stress values are interpolated at the identical 64-isoparametric shape function space locations. Averaged nodal stress values are used for the stress interpolations.

3.4.3 MAGOPT VAX/VMS Command Procedure Example

There is a VAX/VMS version of MAGOPT. In order to execute MAGOPT on the VAX, the MAGNA output MPOST file must be transferred to the VAX. The MAGNA input data file must also be available to input nodal temperatures to MAGOPT and a SAVEME input data file may also required (see Section 3.4.1). The VAX/VMS MAGOPT execution time will be greater but acceptable in most cases. The VAX/VMS version of MAGOPT uses double precision to interpolate within elements and compute all Hyperpatches, but the nodal stress averaging is performed in single precision. This potentially reduces the precision of the stress Data Hyperpatch coefficients.

Table 3.4 is an example of a command file for running MAGOPT on a VAX/VMS system. The files assigned in Table 3.4 are described in Table 3.5.

TABLE 3.4

MAGOPT EXECUTION VAX/VMS COMMAND FILE LISTING

```
$ ASSIGN USERA:[OPTRAN.COCKPIT]CANOPY.MP      MAGNPO
$ ASSIGN USERA:[OPTRAN.COCKPIT]CANOPY.MAGDAT  MAGDAT
$ ASSIGN USERA:[OPTRAN.COCKPIT]SAVEME.DAT     SAVEME
$ ASSIGN USERA:[OPTRAN.COCKPIT]CANOPY.OP      OPOST
$ ASSIGN USERA:[OPTRAN.COCKPIT]CANOPY.AP      APOST
$ RUN [OPTRAN.MAGOPT]MAGOPT
PRINT=NO  SAVE
```

TABLE 3.5

MAGOPT INPUT AND OUTPUT FILE DEFINITIONS

FILE	DESCRIPTION
CANOPY.MP	MAGNA results summary data MPOST file described in Section 5.7 of Reference 4
CANOPY.MAGDAT	MAGNA input data described in detail in Section 8 of Reference 4
SAVEME.DAT	File Generated by PATMAG containing nodal and element number equivalence data
CANOPY.OP	OPOST file generated by MAGOPT for input to OPTRAN described in Section 3.5 of this report
CANOPY.AP	Nodal averaged MAGNA results APOST file described in Section 5.7 of Reference 4

The VAX/VMS version of MAGOPT reads input data from the source defined by the logical symbol SYS$INPUT which is the command file itself as indicated by the last line of Table 3.4, the single input data card. The VAX/VMS version of MAGOPT writes output to the logical symbol SYS$OUTPUT which is the terminal screen if the command file is executed interactively. SYS$OUTPUT is the log file if the command file is submitted to a batch queue.

3.5 PATRAN PRE-PROCESSING OF THE OPOST FILE

The OPOST file generated by MAGOPT is in PATRAN Phase 1 neutral file format. It contains only the header packets (Types 25 and 26), PATRAN Phase 1 geometry modeling Geometric Hyperpatch packets (Type 34), and Data Hyperpatch packets (Type 38). The format of each packet is described in detail in Chapter 29 of Reference 3.

The OPOST file generated by MAGOPT can be input directly to OPTRAN to define the deformed model geometry and the stress and temperature fields. No PATRAN Phase 2 nodal or finite element model data are required by OPTRAN; however, PATRAN cannot be used to examine the optical analysis results in this case. Only OPTINT can be used to evaluate results in this case and the rays traced must be defined by user supplied azimuth and elevation input data.

The use of PATRAN to examine optical analysis results requires that new PATRAN Phase 2 nodes and elements be created on the first surface intersected by the incoming light. A new neutral file containing this information must then be created for input to OPTRAN. It is important that a neutral file or the PATRAN data base file containing the entire model including Phase 1 data, Phase 2 data, GFEG tables and CFEG tables be retained. This information must be in the PATRAN data base to permit the use of PATRAN to examine optical analysis results.

If the OPOST input file contains nodal data, the nodal mesh can define the mesh of rays to be traced by OPTRAN. One ray is traced for each node and optical results are computed for each node. OPTRAN creates a PATRAN nodal results neutral file which can be input PATRAN to examine optical analysis results. PATRAN element data are not used by OPTRAN, but is required by PATRAN for the examination of the optical analysis results.

Duplicate nodes are normally created by PATRAN on patch boundaries when a GFEG command is used to pave a region with nodes. Elimination of the duplicate nodes is optional. OPTRAN execution time is reduced linearly with the percent of nodes eliminated. Discontinuities in the optical parameters can occur at patch boundaries if duplicate nodes are not eliminated, but the presence of discontinuities is an indication that the finite element model results may not be sufficiently accurate. Optimizing the node numbering does not affect OPTRAN performance and may have the undesirable effect of scrambling the node numbers.

Another advantage of using PATRAN to pre-process the OPOST file is that PATRAN blending capabilities can be used to smooth out first derivative discontinuities in the geometry that can occur at the original finite element boundaries from which the Geometric Hyperpatches are derived. Geometry first derivative discontinuities can introduce discontinuities in the optics analysis results.

The data from the OPOST file is input to PATRAN through the neutral file interface. The PATRAN user must increase the PATRAN default Data Hyperpatch number limit prior to inputting the file. This can only be done at the time a PATRAN execution is initiated before the generation of the PATRAN data base. PATRAN initially prompts the user for a device mnemonic and then prompts the user with the following;

INPUT "GO", "SES", "HELP", PATRAN EXECUTIVE DIRECTIVE, OR "STOP".

At this point the user must input the following PATRAN Executive Directive;

PATRAN,SIZE:28/40

which increases the PATRAN random access pages for Data Hyperpatches. This is discussed in detail in Chapter 36 of Reference 3.

Any desired geometric blending operations should be performed prior to generating Phase 2 data. Patches should then be created from the initial light incident Geometric Hyperpatches faces which can then be paved with the desired Phase 2 nodes and elements using PATRAN GFEG and CFEG commands. Simple 4 node quad elements have been used effectively in test cases.

3.6 OPTRAN OPERATION

There are currently VAX/VMS and CRAY/COS versions of the OPTRAN optics analysis code. OPTRAN requires two input files. The first is a PATRAN neutral file generated either by MAGOPT or by PATRAN which defines the model geometry and stress and temperature state. The contents of the PATRAN neutral file are described in the previous section and Chapter 29 of Reference 3. The second is a user prepared input file used to select processing options, input optical parameter material properties, and define light entrance and exit surfaces. The contents of this user prepared input file are described in Section 3.7. The following sections describe example execution command procedures for the VAX and CRAY.

3.6.1 OPTRAN VAX/VMS Command Procedure Example

A sample VAX command file for executing OPTRAN is shown in Table 3.6 below. The contents of the respective files are described in Table 3.7.

TABLE 3.6

OPTRAN EXECUTION VAX/VMS COMMAND FILE LISTING

```
$ ASSIGN/USER [OPTRAN.COCKPIT]CANOPY.NOP      PATRAN_DATA
$ ASSIGN/USER [OPTRAN.COCKPIT]CANOPY.RINP     OPTRAN_INPUT
$ ASSIGN/USER [OPTRAN.COCKPIT]CANOPY.LSTND    OPTRAN_OUTPUT
$ ASSIGN/USER [OPTRAN.COCKPIT]CANOPY.OUPND    RESULTS_OUTPUT
$ ASSIGN/USER [OPTRAN.COCKPIT]CANOPY.NTVAXND NEUTRAL_OUTPUT
$ RUN [OPTRAN.CODE]OPTRAN
```

TABLE 3.7

OPTRAN INPUT AND OUTPUT FILE DEFINITION

CANOPY.NOP	PATRAN neutral file with nodal information which defines the input light rays.
CANOPY.RINP	OPTRAN user prepared input file which defines material properties and processing options.
CANOPY.LSTND	OPTRAN listing output file with input summary, error messages, raytrace data, and plot file summary tables.
CANOPY.OUPND	OPTRAN plot output file which contains outline and grid raytrace data for plotting by OPTINT.
CANOPY.NTVAXND	PATRAN nodal results file. The format of the file is described in Section 27.5.2.1 of Reference 4. The column contents are described in Sections 3.9.2 and 3.9.4.

3.6.2 OPTRAN CRAY/COS Job File Example

A sample CRAY (COS) Job File to compile and execute OPTRAN is given in Table 3.8. The OPTRAN input and output files are the same as those described in Table 3.7, with the exception that the PATRAN nodal results file is named CANOPY.NTCRYND instead of CANOPY.NTVAXND to indicate that it was created on the CRAY. The content of both files is the same.

TABLE 3.8

OPTRAN SAMPLE CRAY (COS) JOB FILE

```
JOB,JN=OPTRAN,CL=P2,T=300,US=P890028,MFL.
ACCOUNT,AC=P890028,APW=xxxxxxx,UPW=xxxxxxx.
*. CRAY JOB SUBMISSION
*. OPTRAN OPTICAL ANALYSIS
*. OPTRAN
FETCH,DN=OPTR,SDN=OPTRAN,^
TEXT='DISK$USER03:[P890028.PLATE]OPTRAN.CRY'.
CFT,I=OPTR,L=OPTLIS.
DISPOSE,DN=OPTLIS,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]CFT_OPTRAN.LIS'.
RELEASE,DN=OPTR.
ASSIGN,DN=LOPT,A=FT06.
ASSIGN,DN=ROPT,A=FT04.
ASSIGN,DN=POPT,A=FT18.
FETCH,DN=PATD,SDN=PATDAT,^
TEXT='DISK$USER03:[P890028.PLATE]CANOPY.NOP'.
ASSIGN,DN=PATD,A=FT01.
FETCH,DN=OPTD,SDN=OPTDAT,^
TEXT='DISK$USER03:[P890028.PLATE]CANOPY.RINP'.
ASSIGN,DN=OPTD,A=FT02.
LDR.
DISPOSE,DN=LOPT,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]CANOPY.OUPND'.
DISPOSE,DN=ROPT,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]CANOPY.LSTND'.
DISPOSE,DN=POPT,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]CANOPY.NTCRYND'.
```

3.7 OPTRAN USER INPUT DATA

The OPTRAN input data file is used to describe the optical properties of the windscreen and to request processing options. The optical parameters which must be defined include:

1. Pilot reference coordinate system, including eye position and pilot orientation.
2. Optical material identification for each hyperpatch.
3. Entrance and exit surfaces for each component.
4. Optical properties for each material.

The OPTRAN input file contains control records defining clusters of data items or processing requests. Control records contain a one-line header consisting of an alphanumeric keyword, followed in some control records by numeric parameters, separated by spaces. Each key word (control code) may be up to 8 characters with no embedded blanks. Some control records are followed by auxiliary input data, with data items separated by spaces. The auxiliary data lines following some control records are terminated by blank lines.

Control record data and the auxiliary line data items are read in free format. Individual data items are separated by blanks. Data items in control records follow the key word, separated by one or more blanks. Data items are either character string key words, real values, or integer values. Real data items may optionally contain signs, decimal points, and exponents, but no embedded blanks. Exponents are input according to FORTRAN E format rules as indicated in some of the examples which follow. Integer values may contain only signs and integer characters with no embedded blanks. Values must be input for all data items specified on the line.

If multiple data sets are possible following a control record, a blank line is used to terminate the reading of auxiliary data associated with a particular control record. Auxiliary data must be input in complete sets. The sequencing of the input data stream becomes corrupted if lines are omitted from multiple line data sets. Comment lines may be inserted in the file. Comment lines start with the alphanumeric code 'C' followed by a space.

The following is a list of input control records and auxiliary data itemized by key word control codes.

1. EYE x y z

An EYE control record must be input to define the central eye location coordinates, which are entered following the key word on the control record line. Three real values are read following the key word. No auxiliary data are read following this control record.

Example:

```
EYE  15.0  30.0  -40.0
```

2. VIEW

VIEW control record precedes auxiliary data which defines the pilot reference axes. These axes define a right-handed coordinate system. The auxiliary data defines direction vectors (in global coordinates) of the pilot reference axes. Three lines of auxiliary data are read and no blank line terminator is required.

The three input lines each contain a character value followed by three real values as follows:

```
X    dx    dy    dz
Y    dx    dy    dz
Z    dx    dy    dz
```

where (dx, dy, dz) is a direction vector that is converted by the code to a unit vector.

Example:

```
VIEW
 X     0.0    0.0   -1.0
 Y     0.0    1.0    0.0
 Z     1.0    0.0    0.0
```

3. MEDIA

A MEDIA control record precedes data which associates Geometric Hyperpatch identification numbers (IDs) with material numbers. Multiple single line auxiliary data sets are read. At least one set is required for each material. A material number must be assigned to each Geometric Hyperpatch. A blank line after the last data set terminates the reading of auxiliary data for this control record.

Each single line auxiliary data set contains the following four integer data items:

```
IMATL  IPAT  JPAT  INCR
```

where IMATL = material ID

IPAT = starting hyperpatch ID

JPAT = ending hyperpatch ID

INCR = increment

IPAT, JPAT, and INCR define a loop analogous to a FORTRAN DO loop, starting at IPAT, ending at JPAT, in increments of INCR. The default increment is 1. A zero value for IMATL is equivalent to a blank line.

Example:

```
MEDIA
     1    1   65    2
     2    2   66    2
     (blank line)
```

4. SURFACE

A SURFACE control record precedes auxiliary data which associates Geometric Hyperpatch ID and face numbers with a surface ID numbers. As many single line auxiliary surface identification data sets as necessary may be input. Reading is terminated by blank line following the last line.

Each auxiliary data line contains the following six integer data values:

```
IMATL  ISURF IFACE IPAT  JPAT  INCR
```

where IMATL = material ID

ISURF = surface ID

IFACE = face number (1-6)

IPAT = starting hyperpatch ID

JPAT = ending hyperpatch ID

INCR = increment

IPAT, JPAT, and INCR define a loop analogous to a FORTRAN DO loop, starting at IPAT, ending at JPAT, in increments of INCR. The default increment is 1. A zero value for IMATL is equivalent to a blank line.

Example:

```
SURFACE
     1    1    5    1    65    2
     2    2    6    2    66    2
 (blank line)
```

5. PART

A PART control record precedes auxiliary data which defines the order of components (parts) and the entrance and exit surfaces for each component, counting from the outside of the aircraft to the eye. PART input is not required for a system with only one component. OPTRAN considers a component to be a collection of connected Geometric Hyperpatches, possibly containing multiple layers, with an entrance face and an exit face. The reading of the single line data sets is terminated by a blank line.

Each single line auxiliary data set contains the following four integer data items:

ICOMPN KENTRY KEXIT KTRAN

where ICOMPN = component ID

KENTRY = entry surface ID

KEXIT = exit surface ID

KTRAN = transmission code

0 component cannot be bypassed

1 component can be bypassed

A zero value for ICOMPN is equivalent to a blank line.

Example:

```
PART
     1    1    2    0
     (blank line)
```

6. MPROP

An MPROP control record precedes auxiliary data which defines sets of isotropic optical material properties characterized by a single index of refraction, thermal coefficient of refraction, and two independent stress-optic coefficients. Orthotropic optical material properties must be input through the use of ORTHO control records and their associated auxiliary data sets. Multiple single line isotropic material property auxiliary data sets may be input. Either an isotropic or an orthotropic material property data set must be input for each material. Reading is terminated by a blank line following the last set.

Each single line auxiliary data set contains the following integer and four real data items:

IMATL, RINDX, DNDT, Q11, Q12

where IMATL = material ID
RINDX = index of refraction
DNDT = temperature coefficient of refractive index
Q11 = stress-optic coefficient
Q12 = stress-optic coefficient

A zero value of IMATL is equivalent to a blank line.

Example:

```
MPROP
1     1.50     4.8E-5    2.1E-12   1.7E-12
2     1.615    4.2E-5    3.2E-12   2.8E-13
(blank line)
```

7. ORTHO

An ORTHO control record precedes auxiliary data which defines sets of orthotropic material properties. Multiple eleven line auxiliary data sets of properties may be input. Complete eleven line data sets must be input to avoid corrupting the input data stream. Input is terminated by a blank line following the last eleven line set.

Line 1 of the data set contains the following three integer items:

IMATL IUVWAX IOPMTR

where IMATL = material ID

IUVWAX = 0 to use global X,Y,Z as reference axes

= 1 to use parametric parameters to derive reference axes

IOPMTR = 0 optical axes are equivalent to reference axes.

= 1 use OPMATR (defined below) to define material axes with respect to reference axes.

Line 2 of the data set contains the following six real items:

RNX RNY RNZ DNXDT DNYDT DNZDT

where RNX, RNY, RNZ = orthotropic indices of refraction with respect to material axes.

DNXDT, DNYDT, DNZDT = orthotropic dn/dT coefficients

Lines 3, 4, and 5 contain three real values on each line which defines the orientation of the optic axes with respect to the reference axes. The following data item is read from the respective lines:

OPMATR

where OPMATR is a 3 x 3 direction cosine matrix. Let (V1, V2, V3) be the principal material axes with respect to the reference axes. V1, V2, and V3 are read from the respective lines.

Lines 6 through 11 contain 6 real values on each line. The following data item is read from the respective lines:

STCOEF

where STCOEF is the 6 x 6 matrix of stress-optic coefficients. Each input line is a line of the matrix respectively.

Example:

```
ORTHO
     2    0    0
1.51  1.505 1.500  4.5E-5  4.5E-5  4.5E-5
1.0    0.0   0.0
0.0    1.0   0.0
0.0    0.0   1.0
1E-12   3E-13  3E-13  0.0      0.0      0.0
3E-13   1E-12  3E-13  0.0      0.0      0.0
3E-13   3E-13  1E-12  0.0      0.0      0.0
0.0      0.0    0.0  1.5E-13   0.0      0.0
0.0      0.0    0.0  0.0     1.5E-13    0.0
0.0      0.0    0.0  0.0       0.0  1.5E-13
         (blank line)
```

3.8 OPTRAN PROCESS EXECUTION CONTROL OPTIONS

The control records described in this section determine which OPTRAN processing options are executed and what output is generated. The control records have the same general format as the input control records described in the previous section. However, there is no auxiliary data associated with the process execution control records.

These control records must follow a complete set of input control records. During any one run, however, control records may be repeated. If an input record is repeated, the new data replaces the old data. If an processing control record is repeated, the execution called for by that option is repeated.

Output may be produced on the listing file, the OPTRAN plot file, and/or the PATRAN nodal results file. The output to the PATRAN nodal results file may be in either of the two formats described in Sections 3.9.2 and 3.9.4 of this report, respectively. Some of the process execution control records contain data required for the execution of a particular option. The rules for the input of this data are the same as rules for the input data control records.

Following is a list of output codes.

1. AXES azmin azmax azstp elmin elmax elstp

An AXES control record defines a set of chart labels for OPTINT plots. Azimuth and elevation refer to direction angles relative to the Pilot Z axis. The user may also define or change these values from within OPTINT. Six real values are read from the control record.

where azmin = minimum azimuth angle
azmax = maximum azimuth angle
azstp = azimuth label increment
elmin = minimum elevation angle
elmax = maximum elevation angle
elstp = elevation label increment

Example:

```
AXES  0.0  20.0  5.0   0.0  40.0  10.0
```

2. OUTLINE

An OUTLINE control record generates the outline of each entrance surface as observed from the pilot reference system. Unconnected hyperpatch edges are output to the OPTRAN plot output file. The outline indicates the limits to the field of view. The results are written to the OPTINT file.

Example:

```
OUTLINE
```

3. EVAL npat u v w

An EVAL control record requests calculation of the 3D location, stress, temperature, index ellipsoid, and direction angles for the specified Geometric Hyperpatch ID and parametric coordinates. An integer and three real values are read from the control record. This processing option was included primarily as a debugging tool. Check values of stress, temperature, and global coordinates for specified Geometric Hyperpatch parametric coordinates are written to the listing file.

where npat = hyperpatch ID

u = hyperpatch parametric parameter

v = hyperpatch parametric parameter

w = hyperpatch parametric parameter

Example:

```
EVAL 156  0.5   0.5   1.0
```

4. FIND az el

A FIND control record requests that the point of intersection with the face of the closest Geometric Hyperpatch be computed for a vector from the eye in the direction specified. The direction is specified by the angles read as two real values from the FIND control card. The global coordinates of the point of intersection are sent to the listing file. This option is also a debugging tool. It may produce output under circumstances (such as improper input data) where a RAY option fails.

where az = azimuth direction angle (degrees)

el = elevation direction angle (degrees)

Example:

```
FIND 20.0  25.0
```

5. RAY az el

A RAY control record generates a surface-by-surface raytrace for the direction angles read as two real values from the control card. The output is sent to the listing file.

where az = azimuth direction angle (degrees)

el = elevation direction angle (degrees)

Example:

```
RAY  20.0  25.0
```

6. RESULTS

A RESULTS control record requests the generation of a PATRAN nodal analysis file, described in Section 3.9.2. Generally this option appears without parameters and by default rays are traced for all nodes on the input OPOST file. There is an optional form of the request that processes a restricted range of nodes and is useful for testing purposes:

```
RESULTS n1  n2  n3
```

where (n1, n2, n3) define the parameters of a node selection loop like a FORTRAN DO loop. Here n1 is the starting node, n2 is the end node (default n1), and n3 is the increment (default 1).

Multiple RESULTS control records may be included in the input file, corresponding to different eye positions and/or material parameters, but this results in a single output file of concatenated data sets. PATRAN can only handle the first set of data. A text editor can be used to fragment a multiple data set results file into individual data files for processing by PATRAN.

Example:

```
RESULTS
```

7. GRID azmin azmax azstp elmin elmax elstp

A GRID control record causes the generation of a rectangular mesh of rays at equally spaced angles. Six real values are read from the control card. There are five rays traced for each grid point. The data are written to the OPTRAN plot file (See Section 3.9.3) and a one-line summary is written to the listing file. This mesh of rays is the basic information used to construct the plots in OPTINT. Choosing too fine a mesh will result in dense plots and very long run times. Angle increments of 5 or 10 degrees are suggested. Smaller steps may be appropriate for a narrow field of view.

where azmin = minimum azimuth angle
      azmax = maximum azimuth angle
      azstp = azimuth increment
      elmin = minimum elevation angle
      elmax = maximum elevation angle
      elstp = elevation increment

Example:

```
GRID  -40.0  40.0  10.0    0.0  50.0  10.0
```

8. CHECK

A CHECK control record requests the generation of a PATRAN nodal results file, as described in Section 3.9.4. The columns in this PATRAN nodal results file contain displacement, stress, and temperature results at nodes. The information was originally used to test the OPTRAN code, but can also be used as a tool for checking the consistency of the input data from a finite element run. The CHECK control record and RESULTS control records cause output to the same file which results in concatenated data sets if both are read during a single execution of OPTRAN. Only the first set of data can be manipulated by PATRAN.

Example:

```
CHECK
```

3.9 OPTRAN OUTPUT FILES

This section describes the contents of the three different types of OPTRAN output files: the OPTRAN listing file, PATRAN nodal results file, and OPTRAN results file.

3.9.1 OPTRAN List File

The OPTRAN listing file contains a formatted echo of input parameters, error messages, summary tables from RESULTS and GRID requests, and ray data listings. This section discusses the content of the ray data listings. The reader is expected to have a basic knowledge of optics and polarization, which can be obtained from the OPTRAN Theoretical Manual (Reference 1) and the references listed there.

Table 3.9 is an example OPTRAN ray data listing. The test case was an undeformed, unstressed flat plate. The first line of the table is an echo of the OPTRAN input file showing the RAY request. The conventional azimuth and elevation angles are shown on the next line. The conventional definitions are not used in OPTRAN because of the nonsymmetric mapping to linear coordinates.

TABLE 3.9

OPTRAN RAY DATA LISTING

```
RAY 9.063 4.226

Target Azimuth       9.079     Elevation       4.208

      Target orientation      Angular Deviation
     x-angle     y-angle     x-angle     y-angle
       9.063       4.226        .000        .000

              xap          yap          x eye          y eye          z eye
           .00000       .00000         10.011           .027          -.057
           .10000       .00000         10.011           .117          -.015
           .00000       .10000          9.994          -.015           .032
           .00000       .06436         10.000           .000           .000

 Differential output:      -.422591     .906280
                           -.892510    -.416170
         Determinant:       .984733

      Target orientation      Angular Deviation
     x-angle     y-angle     x-angle     y-angle
       9.063       4.226        .000        .000

Mueller matrix:  .902884      -.002612       .000887
.001436                 .002358       -.569966       .700105
.013719                 .001431       -.006305      -.022815
.902570                -.001436        .700212       .569670
.019289

Output polarization state:
   .34% polarized light of magnitude       .902884
Left-handed elliptical polarization of   -.245
oriented at 15.62 degrees
```

TABLE 3.9 (continued)

```
List of ray intersections
         1       0        0       0        0       0
   0.0000000E+00  0.0000000E+00  0.0000000E+00
  -9.8380820E+03  7.3383730E+02 -1.5737737E+03
   9.8480708E-01 -7.3386409E-02  1.5738311E-01
   9.8480708E-01 -7.3386409E-02  1.5738311E-01
   0.0000000E+00  9.0631339E-01  4.2260624E-01
   0.0000000E+00  0.0000000E+00  0.0000000E+00
   1.0000000E+00  0.0000000E+00  9.9898571E+03  1.0000000E+00
         2       1        5       1        1       0
   5.1295930E-01  2.3918857E-01  0.0000000E+00
   1.1102233E-12  7.1756571E-01 -1.5388779E+00
   1.5647869E+00 -7.3386409E-02  1.5738311E-01
   9.9389859E-01 -4.6612511E-02  9.9964313E-02
  -4.7369041E-02 -9.9886380E-01  5.2239979E-03
   1.0000000E+00  0.0000000E+00  0.0000000E+00
   1.5743930E+00 -4.9019010E-02  1.0061389E+00  9.5020137E-01
         3       1        6       0        2       0
   4.7943331E-01  2.2355568E-01  1.0000000E+00
   1.0000000E+00  6.7066705E-01 -1.4382999E+00
   9.8480708E-01 -7.3386409E-02  1.5738311E-01
   9.8480708E-01 -7.3386409E-02  1.5738311E-01
   0.0000000E+00  9.0631339E-01  4.2260624E-01
   1.0000000E+00  0.0000000E+00  0.0000000E+00
   1.0000000E+00  0.0000000E+00  9.1388457E+00  9.0288265E-01
         4       0        0       0        0       0
   0.0000000E+00  0.0000000E+00  0.0000000E+00
   1.0000000E+01 -1.6840489E-08  3.6115504E-08
   9.8480708E-01 -7.3386409E-02  1.5738311E-01
   9.8480708E-01 -7.3386409E-02  1.5738311E-01
   0.0000000E+00 -9.0631339E-01 -4.2260624E-01
   1.0000000E+00  0.0000000E+00  0.0000000E+00
   1.0000000E+00  0.0000000E+00  0.0000000E+00  9.0288265E-01
       Focus        Y av      X av      rms R      rms Y      rms
X  -9999.6292     .0000    -.0644     .0000      .0000      .0000
sagittal-mag      1.0000    tangential-mag      1.0000
```

The target orientation and angular deviation errors for a direct ray aimed at the eye are shown in the next few lines. This is followed by a list of differential rays. The first line of this list is the direct ray. It misses the eye (10, 0, 0) by a small error. The next two differential rays show the effects of varying the sagittal (xap) and tangential (yap) components of the target ray direction. The last differential ray is the correction needed for a ray from the target to exactly intersect the eye point. This is a pure tangential correction, as would be expected by symmetry. The tangential plane is the plane containing the object point and the axis of symmetry (optic axis).

The differential ray intersections are used to form a matrix which is inverted to find the ray correction. This matrix and its determinant are shown next. This information was used during program development, and has no obvious physical interpretation.

The next few lines show the target orientation and angular deviation of the corrected ray. The significance of this part of the output listing is that, for many geometries, the angular deviation is significantly different for the corrected ray than for the direct ray. This was contrary to our original hypothesis that the effects of correction would be small for common optical configurations. For the example in Table 3.9, the angular deviation is so small that no differences are apparent.

The next part of the data listing is the Mueller matrix relating the input polarization state to the output polarization state. The Mueller matrix is a 4 x 4 matrix of real coefficients.

An input Stokes vector of representing unpolarized incident light of unit intensity is applied to this Mueller matrix, and the next few lines of data describe the state of polarization of the output. This conveys information about the transmittance, fraction polarized, ellipticity (left or right), and orientation of polarization. The output Stokes vector characterizes the complete polarization state of a ray.

The next part of the listing is a concise dump of surface-by-surface raytrace data. The content of this part of the listing is further described in Table 3.10. These data are of considerable diagnostic value. For example, if the surfaces have been properly numbered, the distance to next surface value should always be a positive number. Layers contributing to stress birefringence will have significant nonzero values for differential index of refraction (difference in index between the two orthogonal polarizations for a specified propagation

TABLE 3.10

OPTRAN RAY INTERSECTION DATA

vertex #	hyperpatch ID	face	Matl #	Surf #	Failure code
2	1	5	1	1	0

Hyperpatch Position:

u	v	w
5.1295930E-01	2.3918857E-01	0.0000000E+00

x	y	z
1.1102233E-12	7.1756571E-01	-1.5388779E+00

Optical direction cosines (magnitude = index of refraction):

k_x	k_y	k_z
1.5647869E+00	-7.3386409E-02	1.5738311E-01

Ray direction cosines (unit vector):

r_x	r_y	r_z
9.9389859E-01	-4.6612511E-02	9.9964313E-02

Polarization reference axis (unit vector):

d_x	d_y	d_z
-4.7369041E-02	-9.9886380E-01	5.2239979E-03

Surface normal (unit vector):

N_x	N_y	N_z
1.0000000E+00	0.0000000E+00	0.0000000E+00

mean refractive index	differential index	distance to next surface	mean attenuation
1.5743930E+00	-4.9019010E-02	1.0061389E+00	9.5020137E-01

direction). The parametric data show which hyperpatches have been intersected, the face number, and parametric/global coordinates of the intersection point. The global intersection points could be used to plot the path of individual rays through a transparency.

Following the surface-by-surface data is an analysis of the apparent image point, obtained by projecting a cluster of differential rays back to their virtual origin. The Focus parameter is the distance to that point. The rms values would give aberration information if real rays were used, but for differential rays the difference in magnitude between rms X and Y values is related to astigmatism. However, this relationship has not yet been fully evaluated in OPTRAN.

Finally, the angular magnification for sagittal and tangential directions is calculated, using differential rays. An ideal transparency, with no curvature, would have unit angular magnification. The significance of these values is still being investigated.

3.9.2 OPTRAN Output Nodal Results File Contents

Table 3.11 lists the contents of the columns contained in the PATRAN nodal results file generated by a RESULTS option in the OPTRAN input file. Many of the columns are obtained by simple operations on other columns. For example, the angular deviation components are the difference between the actual target direction and apparent target direction. The total angular deviation A in column 1 is given by $A = SQRT(A2^2_x + A2^2_y)$, where A_x is column 2 and A_y is column 3. Section 1 of the OPTRAN Theoretical Manual should be consulted for definitions of the optical variables found in this file.

TABLE 3.11

OPTRAN NODAL RESULTS FILE COLUMNS

Column	Description
1	angular deviation (deg) between apparent target direction and actual target direction
2	x-angular deviation (deg)
3	y-angular deviation (deg)
4	transmittance S_0
5	polarization S_p = SQRT(S_1* S_1 + S_2* S_2 + S_3 * S_3)
6	Stokes parameter S_1
7	Stokes parameter S_2
8	Stokes parameter S_3
9	tangential magnification
10	sagittal magnification
11	Apparent x-direction angle (deg)
12	Apparent y-direction angle (deg)
13	Actual x-direction angle (deg)
14	Actual y-direction angle (deg)

3.9.3 OPTRAN Optical Results File Contents

An OPTRAN optical results file is an alphanumeric formatted file with fixed format records. An extract from a typical file is shown in Table 3.12. Spaces have been removed so that the listing can fit on a single report page without reduction. The relative alignment of data columns has been preserved. Options that may appear in the file include an AXES record, OUTLINE records, and GRID records.

The AXES record defines the labeling of the x and y axes of plots. The parameters are X_{min}, X_{max}, X_{inc}, Y_{min}, Y_{max}, Y_{inc}.

OUTLINE records identify the edges of the field of view. An OUTLINE consists of a set of edge records followed by an END record. EDGE records identify a hyperpatch ID and edge number (following PATRAN conventions for edge numbering) and a polyline of four points along the curvilinear edge boundary.

GRID records define a number of rays, number of azimuth columns, and number of elevation rows. There are five rays for each row-column intersection. The data for each ray includes the target direction angles, a ray failure code, x- and y-angular deviations on one line and the four Stokes parameters on a second line. A failure code of 100, as shown in Table 3.10, indicates that the ray is blocked before reaching the eye.

3.9.4 OPTRAN Check File Contents

The OPTRAN consistency check nodal results output file is a set of data items that affect the optical properties of a transparency, but which are not optical variables. Optical effects are the integrated result of rays propagating from a target point to the eye. The data generated on the check file are point properties at the nodes, including temperature, stress, and the direction of the surface normal. These files were generated in the process of testing the OPTRAN results. Table 3.13 lists the contents of the CHECK data file. The data file has the format of a PATRAN nodal results file and can be plotted within PATRAN.

TABLE 3.12

EXTRACT FROM OPTRAN PLOT OUTPUT FILE

```
AXES      .0000    40.0000    10.0000      .0000    40.0000    10.0000
OUTLINE
SURFACE    1
PATCH    1   EDGE    1   LINE
    .0000      .0000       5.7106        .0000      11.3099
    .0000    16.6992        .0000
PATCH    1   EDGE    5   LINE
      .0000      .0000        .0000       5.7106        .0000
    11.3099      .0000     16.6992
PATCH    3   EDGE    8   LINE
    41.9872      .0000     40.5487      10.8966      36.3773
    20.9671    29.6894     29.6894
END
GRID   125     5     5
  .000   40.000    0  .00034     .00223
                      .89352    -.06906     .00000     .00000
-3.333   40.000  100

 3.333   40.000    0  .00032     .00228
                      .89333    -.06889     .00516    -.00400
  .000   43.333  100
```

TABLE 3.13
OPTRAN CHECK NODAL RESULTS FILE COLUMNS

Column	Description
1	temperature
2	x-direction angle (deg)
3	y-direction angle (deg)
4	Pilot reference x-coordinate
5	Pilot reference y-coordinate
6	Pilot reference z-coordinate
7	Stress SIGMA
8	Stress SIGMA
9	Stress SIGMA
10	Stress SIGMA
11	Stress SIGMA
12	Stress SIGMA
13	Global x node coordinate
14	Global y node coordinate
15	Global z node coordinate
16	Surface normal x component
17	Surface normal y component
18	Surface normal z component

3.10 PATRAN PROCESSING OF THE NODAL RESULTS FILE

The Nodal Results File format is described in Chapter 27.5.2.1 of Reference 3. Chapter 27 of the PATRAN User's Manual (Reference 3) describes an impressive variety of capabilities for graphically displaying the contents of this type of file. Examples of PATRAN generated output are shown in Section 4 of this report.

It is important to note that nodes on the incident surface must have been added to the model as described in Section 3.5 of this report in order to use PATRAN to display optical analysis results.

3.11 OPTINT OPTICAL ANALYSIS RESULTS POST-PROCESSING

OPTINT is an interactive program for plotting optical results from OPTRAN. OPTINT uses DISSPLA to generate two-dimensional charts of grid distortion, angular deviation, and polarization ellipses as a function of azimuth and elevation direction angles.

OPTINT uses an optical results file produced by OPTRAN. It checks first for a logical file with the name OPTRAN_RESULTS. If this file is not assigned, OPTINT asks the user to enter a filename. The user is then presented a menu asking for a plot device to be selected. The choice of devices is installation dependent.

The main menu shown below appears after a plot device is selected:

```
OPTINT PLOT OPTIONS
  1  Change axes
  2  Outline Field of View
  3  Distorted grid
  4  Angular deviation
  5  Polarization ellipses
  8  Change plot device
  9  Quit

Enter selection:
```

Selection 1 results in another menu which allows the user to change the scales of the x and y axes. Selections 2 through 5 produce plots. Selection 8 allows a new plot device to be chosen. Selection 9 exits the program.

Selections 4 and 5 query the user for a multiplicative scale to enhance the sensitivity of the plot.

Since the procedure for compiling and linking OPTINT with DISSPLA is unusual, an example command file for this procedure is given here:

```
$! Example command file to link shareable DISSPLA 11.0
$! to DISSPLA_DRIVER
$ FORT OPTINT
$ DEFINE/USER DISSHR11 SYS$LIBRARY:DISSHR11.EXE
$ LINK OPTINT, SYS$INPUT/OPTION
   USERA:[DISSPLA.DIS11.DISSHR]DISSPLA_INIT
   DISSHR11/SHARE
   PSECT_ATTR=$BLANK,PIC,USR,OVR,REL,GBL,NOSHR,NOEXE,RD,WRT,NOVEC
$ EOD
$ EXIT
```

SECTION 4
SAMPLE PROBLEMS

Numerous test cases were run during the development of the OPTRAN code of both stressed and unstressed models with isotropic and orthotropic material properties. Two of these are included as examples. The first is a simple disk with pressure and thermal loads, and the second is a hypothetical layered canopy with pressure and thermal loads. An unstressed visor and heads up display (HUD) are also included in the second example.

Selected results from the two test cases are presented in Sections 4.1 and 4.2. A stress and optical analysis was performed for each example. The stress analysis was run on the CRAY in each case. No finite element thermal analysis was performed for these examples. Nodal temperatures were computed by analytic functions by specially written codes. The optical analysis was run on both a VAX/VMS system and on a CRAY/COS system with matching results.

The stress analysis input data file and stress analysis results output listing file are not included in this report because of their volume and because stress analysis results (while necessary for a rigorous optical analysis) were not a subject of study for this effort. These files were delivered with the software and are available.

4.1 LOADED CIRCULAR FLAT PLATE EXAMPLE

The first example is 9 inch radius circular flat 1-inch-thick disk. The surface of the disk is parallel to the YZ plane and X varies through the thickness. The disk is simply supported on the lower edge (X = 0.0) along its outer circumference. A 15-psi uniform pressure load is applied to one side of the disk in the negative X direction. Temperature (T) is uniform through the thickness of the disk and varies quadratically with radius (r) as

$$R^2 = Y^2 + Z^2 \text{ and } T = 100(1 - 9^2/R^2).$$

This case was run because closed form solutions exist for both the stresses caused by the pressure load and the thermally induced stresses. Table 4.1 shows the MAGNA and MAGOPT CRAY/COS execution job file.

Material properties input MAGNA were:

Young's Modulus	= 450,000 psi
Poisson's Ratio	= 0.3
Coefficient of Thermal Expansion	= 0.0001/deg.

The positive Y axis, negative Z axis quadrant of the disk was modeled with symmetric boundary conditions. Figure 4.1 shows the undeformed geometry of the PATRAN generated finite element model used for the stress analysis. The Geometric Hyperpatches shown in Figure 4.2 were computed by MAGOPT from the deformed geometry of the finite elements shown in Figure 4.1. Figure 4.3 shows the nodal and element meshes generated by the PATRAN post-processing of the OPOST file generated MAGOPT. Rays were traced for each of the nodes indicated by Figure 4.3.

Table 4.2 shows the VAX/VMS DCL execution command file for the PDISK7 example. The contents of the files with matching file name extensions are described in Table 3.7.

Table 4.3 shows the input file established for the disk example. The eye was placed on the axis of the disk to establish a symmetry that can be used to check for the validity of the results.

TABLE 4.1

PDISK7 EXAMPLE MAGNA AND MAGOPT CRAY (COS) JOB FILE

```
JOB,JN=PDISK7,CL=P2,T=60,US=P890028,MFL.
ACCOUNT,AC=P890028,APW=xxxxxxx,UPW=xxxxxxx.
*. CRAY JOB SUBMISSION
*. MAGNA FINITE ELEMENT ANALYSIS
*. MAGOPT STRESS AVERAGING AND DATA CONVERSION
REWIND,DN=$OUT.
FETCH,DN=MAGDAT,SDN=MAGDAT,TEXT=^
'[P890028.PLATE]PDISK7.MAGDAT'.
ASSIGN,DN=MAGDAT,A=FT05.
ASSIGN,DN=MPOST ,A=FT90.
ASSIGN,DN=STIFF ,A=FT12.
ACCESS,DN=MAGNA,PDN=MAGNAEXE,OWN=D840200.
MAGNA.
DISPOSE,DN=$OUT,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]PDISK7.OT'.
RELEASE,DN=FT10:FT12:FT14:FT20:FT98.
FETCH,DN=MOPT,SDN=MAGOPT,TEXT=^
'[P890028.PLATE]MAGOPT.CRY'.
CFT,I=MOPT,L=MOLIS.
DISPOSE,DN=MOLIS,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]MAGOPT.LIS'.
RELEASE,DN=MOPT.
REWIND,DN=MPOST.
REWIND,DN=MAGDAT.
ASSIGN,DN=MAGDAT,A=FT61.
ASSIGN,DN=OPOST,A=FT62.
ASSIGN,DN=MPOST,A=FT90.
ASSIGN,DN=APOST,A=FT98.
FETCH,DN=MOPTIN,SDN=MOPTI,TEXT=^
'[P890028.PLATE]MAGOPT.INP'.
ASSIGN,DN=MOPTIN,A=FT05.
ASSIGN,DN=MOPTOT,A=FT06.
LDR.
DISPOSE,DN=MPOST,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]PDISK7.MP'.
DISPOSE,DN=OPOST,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]PDISK7.COP'.
DISPOSE,DN=APOST,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]PDISK7.CAP'.
DISPOSE,DN=MOPTOT,DC=ST,^
TEXT='DISK$USER03:[P890028.PLATE]MOPDISK7.LIS'.
```

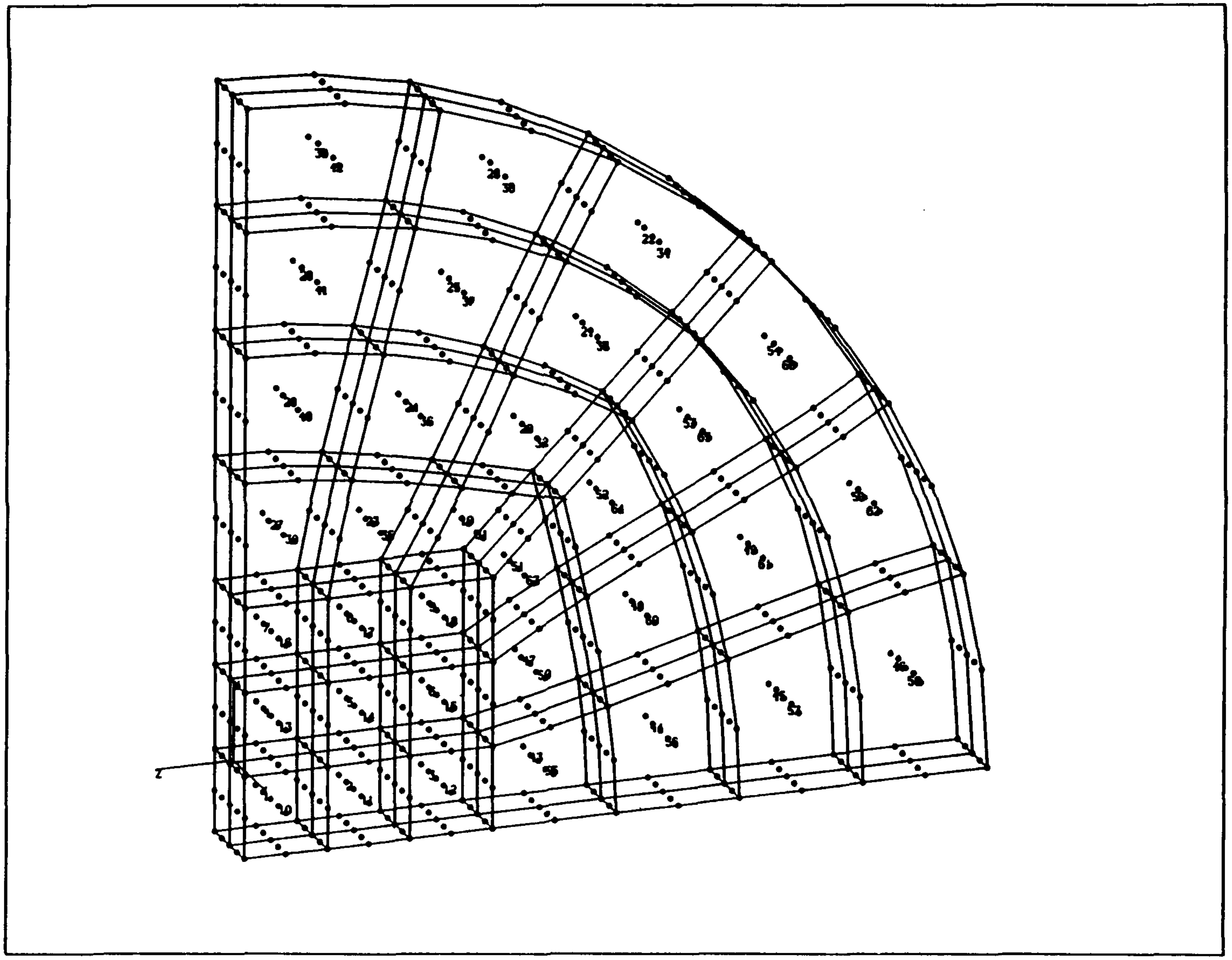

Figure 4.1. The PDISK7 Pressure Disk Example Finite Element Model.

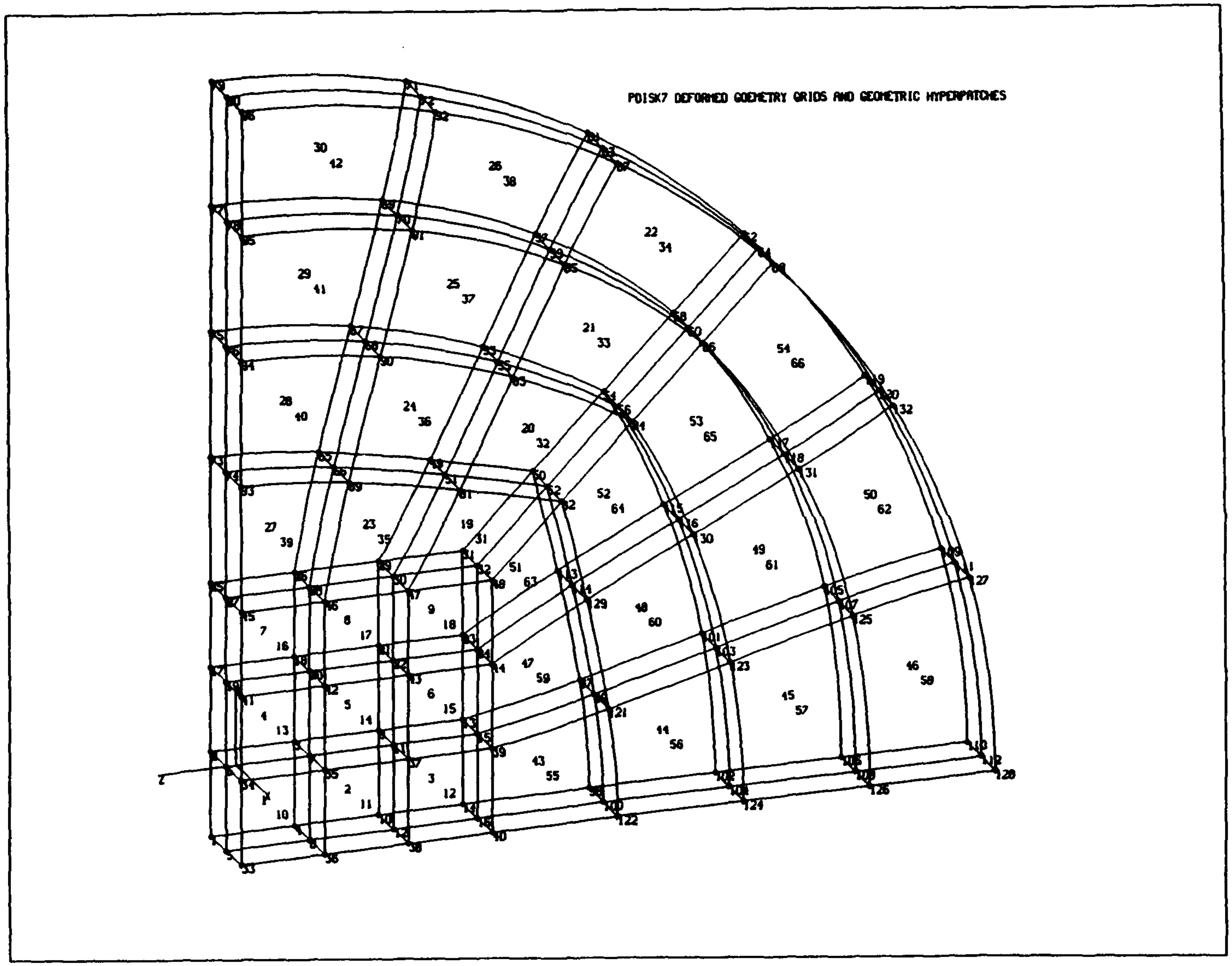

Figure 4.2. The PDISK7 Pressure Disk Example Deformed Geometry Geometric Hyperpatches.

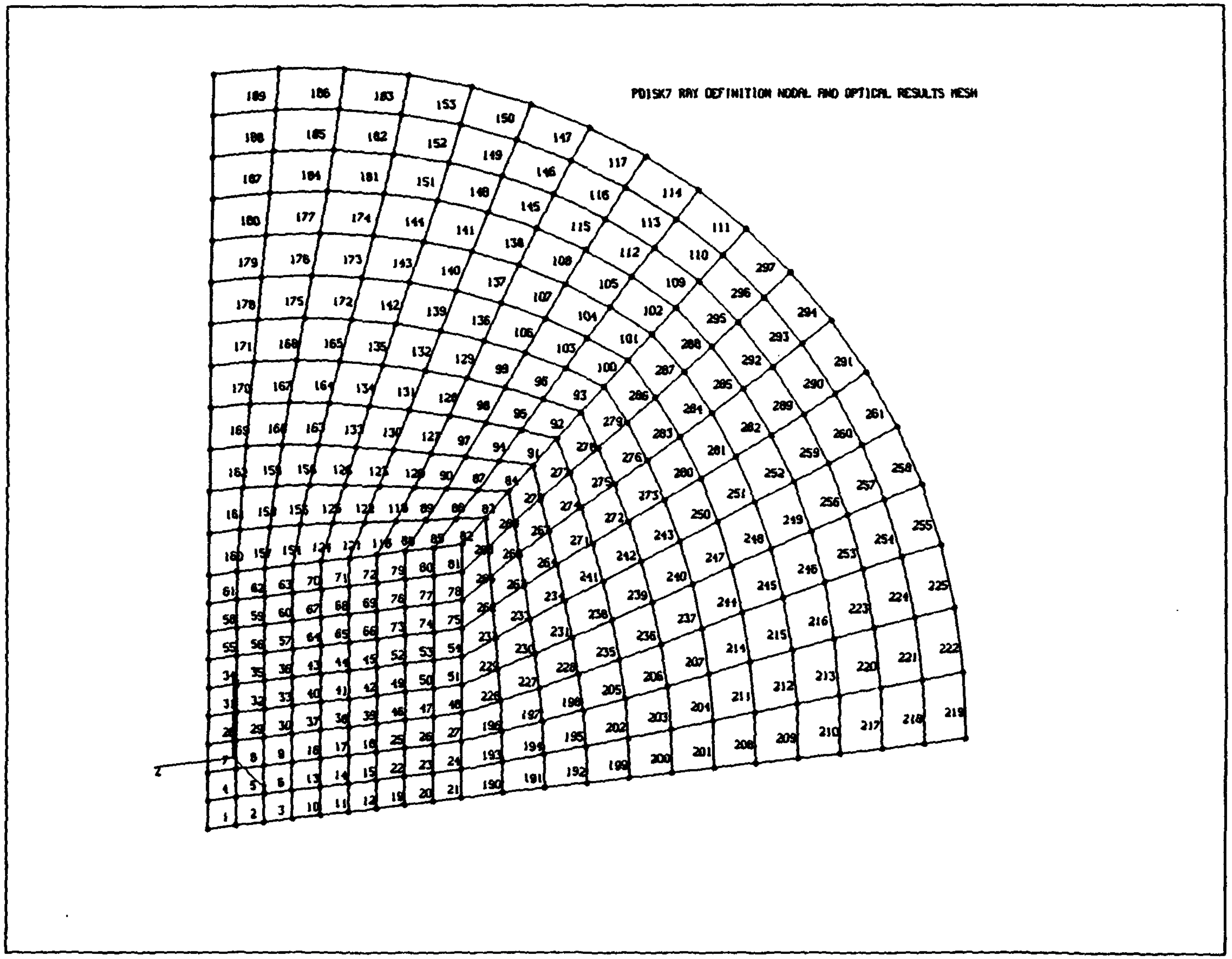

Figure 4.3. The PDISK OPOST File Nodal and Element Mesh.

TABLE 4.2

OPTRAN PDISK7 VAX/VMS DCL COMMAND FILE

```
$ ASSIGN/USER [OPTRAN.DISK]PDISK7.NOP      PATRAN_DATA
$ ASSIGN/USER [OPTRAN.DISK]PDISK7.RINP     OPTRAN_INPUT
$ ASSIGN/USER [OPTRAN.DISK]PDISK7.LSTND    OPTRAN_OUTPUT
$ ASSIGN/USER [OPTRAN.DISK]PDISK7.OUPND    RESULTS_OUTPUT
$ ASSIGN/USER [OPTRAN.DISK]PDISK7.NTVAXND NEUTRAL_OUTPUT
$ RUN [OPTRAN.CODE]OPTRAN
```

TABLE 4.3

OPTRAN PDISK7 INPUT DATA COMMAND FILE

```
C Stress plate test case
EYE   10.0  0.0   0.0
VIEW
 X  0.0  0.0  -1.0
 Y  0.0  1.0   0.0
 Z  1.0  0.0   0.0
MEDIA
    1    1   66

SURFACE
    1    1    5    1    9
    1    1    5   19   30
    1    1    5   43   54
    1    2    6   10   18
    1    2    6   31   42
    1    2    6   55   66

MPROP
    1      1.5     5E-4    3E-8      -2E-8

C   NODE 519
RAY  33.4238  23.3817
C   NODE 520
RAY 34.5026  24.1479
RESULTS
AXES 0 40 10 0 40 10
OUTLINE
GRID 0 40 10 0 40 10
END
```

Figure 4.4 shows the disk as seen by the eye (in angular coordinates). This plot was produced by OPTINT from a data file generated through OPTRAN. At the eye position chosen, the disk subtends a field of view of approximately 45 degrees. This means that the angle of incidence of rays varies from normal incidence on axis (center of the disk) to 45 degree angle of incidence at the edge of the disk. The optical distortion is essentially zero for a flat plate. The angular deviations show have been magnified by a factor of 20. The largest angular deviation is only about 0.15 degrees. Symmetry demands that the angular deviation be axisymmetric, as illustrated in Figure 4.4. Figure 4.5 is a plot from PATRAN using the nodal results file generated by OPTRAN. Column 1 is the magnitude of angular deviation and shows essentially radial contours. Columns 2 and 3 of the nodal results file are the two components of angular deviation, and are plotted in Figures 4.6 and 4.7. The radial profiles are not uniform radially because of the stress and thermal loads applied to the disk.

Figure 4.8 shows the fractional transmittance of the disk, which varies from a maximum of 0.912 to a minimum of 0.909. This should be a axisymmetric function for this example. The losses in transmittance are due to reflections from the front and back surfaces of the disk and are relatively constant over the face of the disk.

Figure 4.9 shows the polarization ellipse at different locations on the disk. The scale was magnified to make the ellipses more visible. In previous runs, when the stress-optic coefficients were set to zero, there is no birefringence and all of the polarization ellipses reduced to straight radial lines, indicating linear polarization aligned with the plane of incidence. Even in the presence of stress birefringence, there is no effect where the stresses are aligned with the plane of incidence (at 0, 45, and 90 degrees). The degree of polarization and values of Stokes parameters are shown in Figures 4.10 through 4.13. These plots demonstrate the consistency of the polarization calculations over a range of angles and orientations.

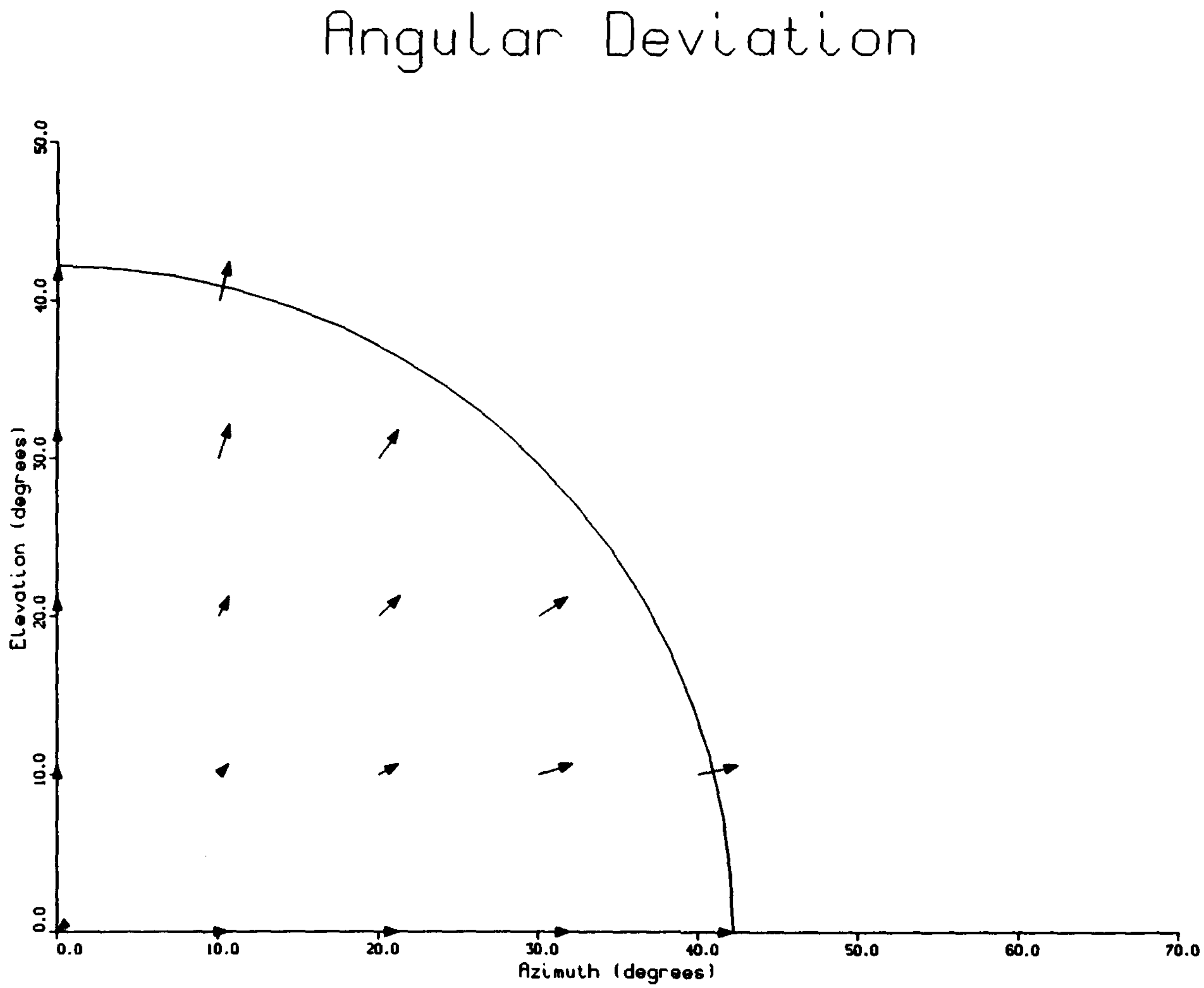

Figure 4.4. Angular Deviation vs. Angle for PDISK7 Example.

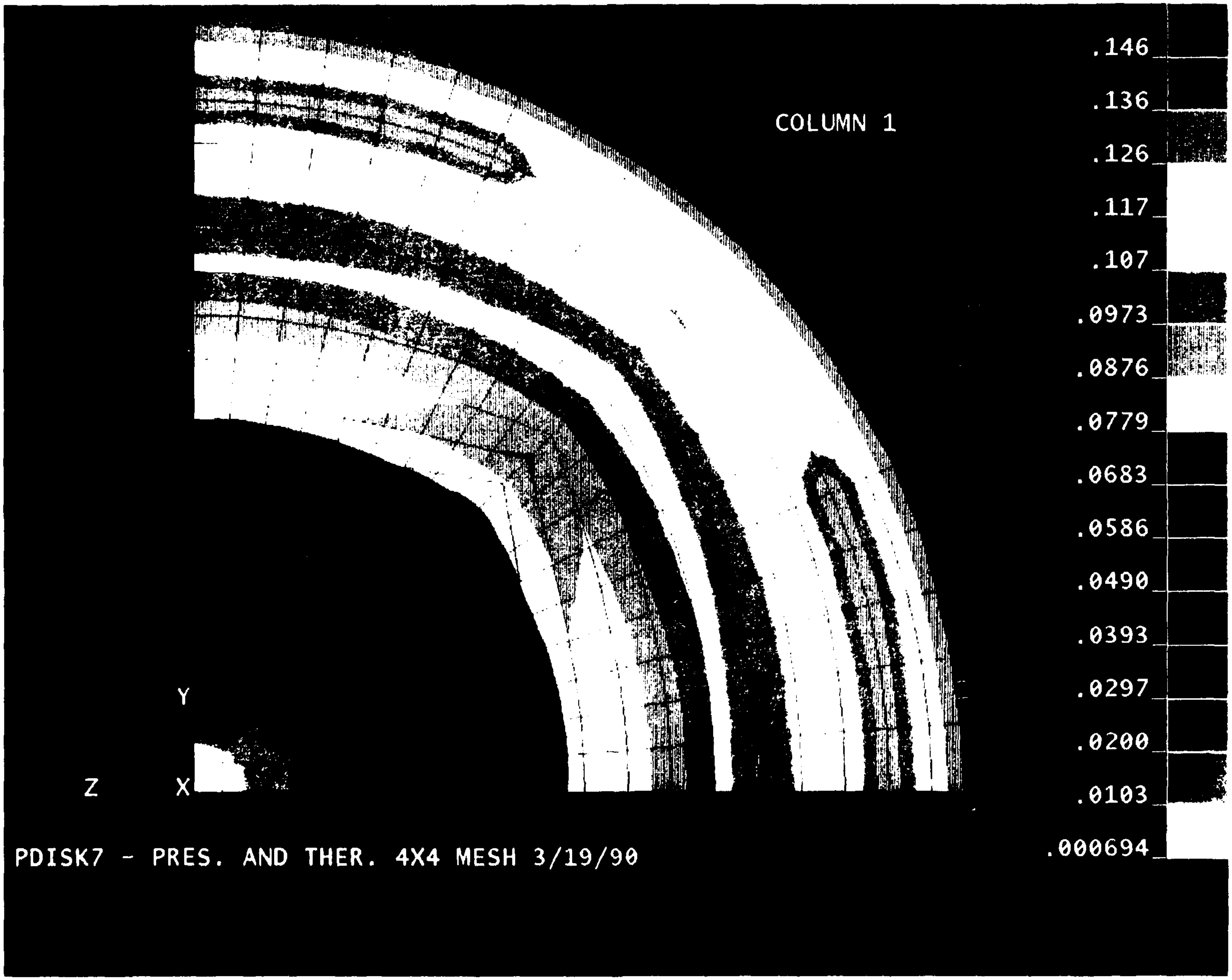

Figure ..5. PATRAN Nodal Results (Column 1 Angular Deviation) for PDISK7 Example

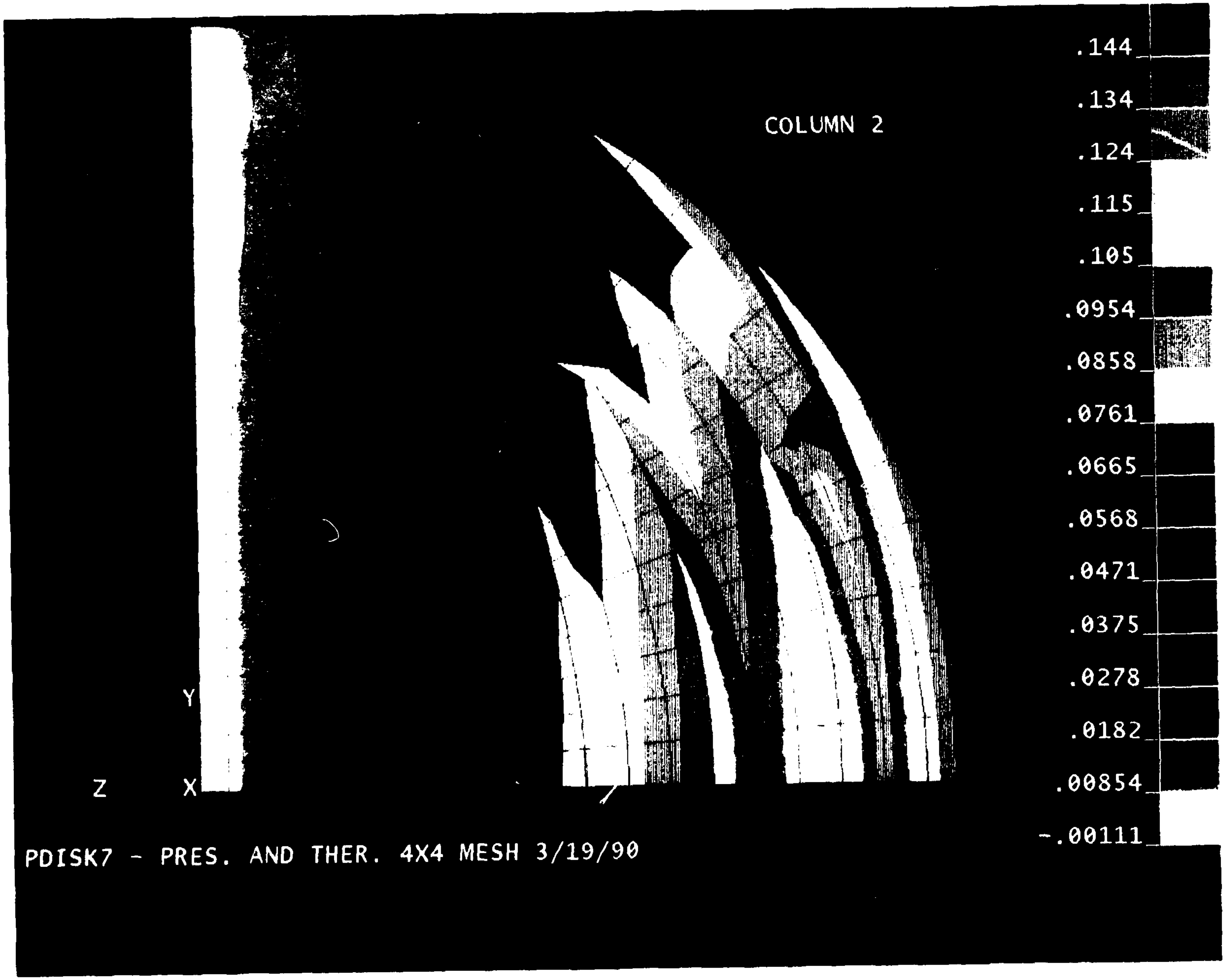

Figure 4.6. PATRAN Nodal Results (Column 2 Azimuthal Component of Angular Deviation) for PDISK7 Example

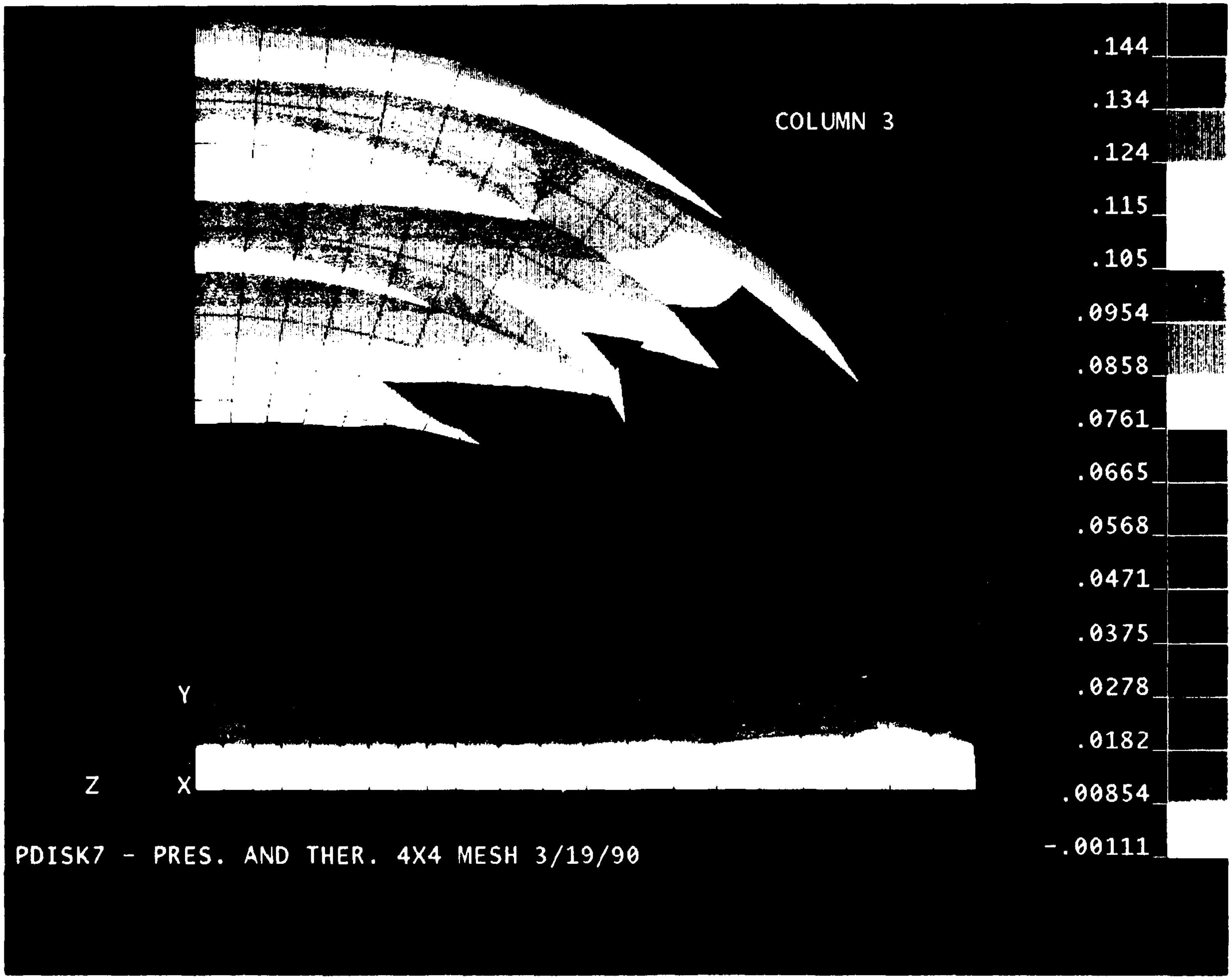

Figure 4.7. PATRAN Nodal Results (Column 3 Elevation Component of Angular Deviation) for PDISK7 Example

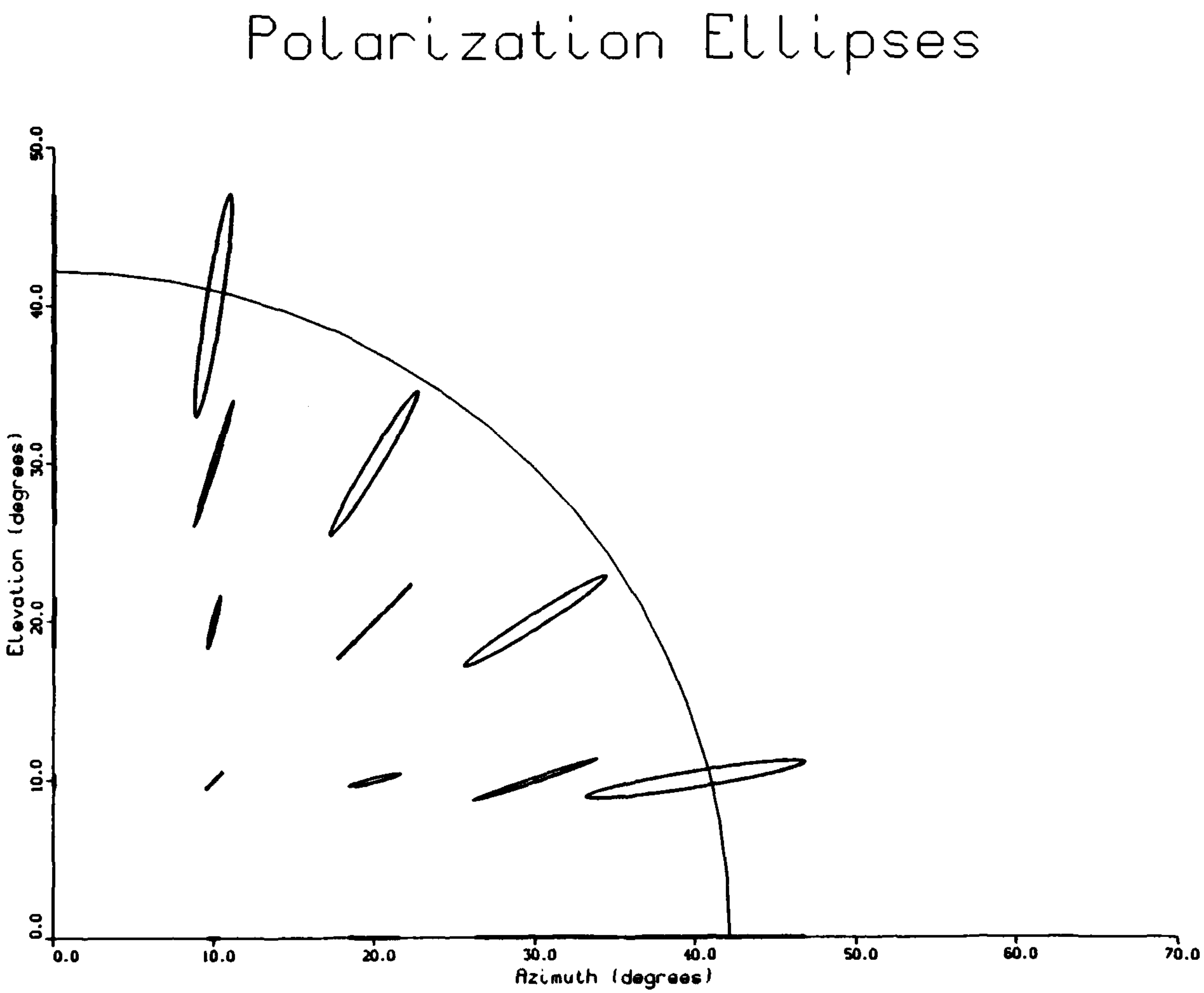

Figure 4.8. Polarization vs. Angle for PDISK7 Example.

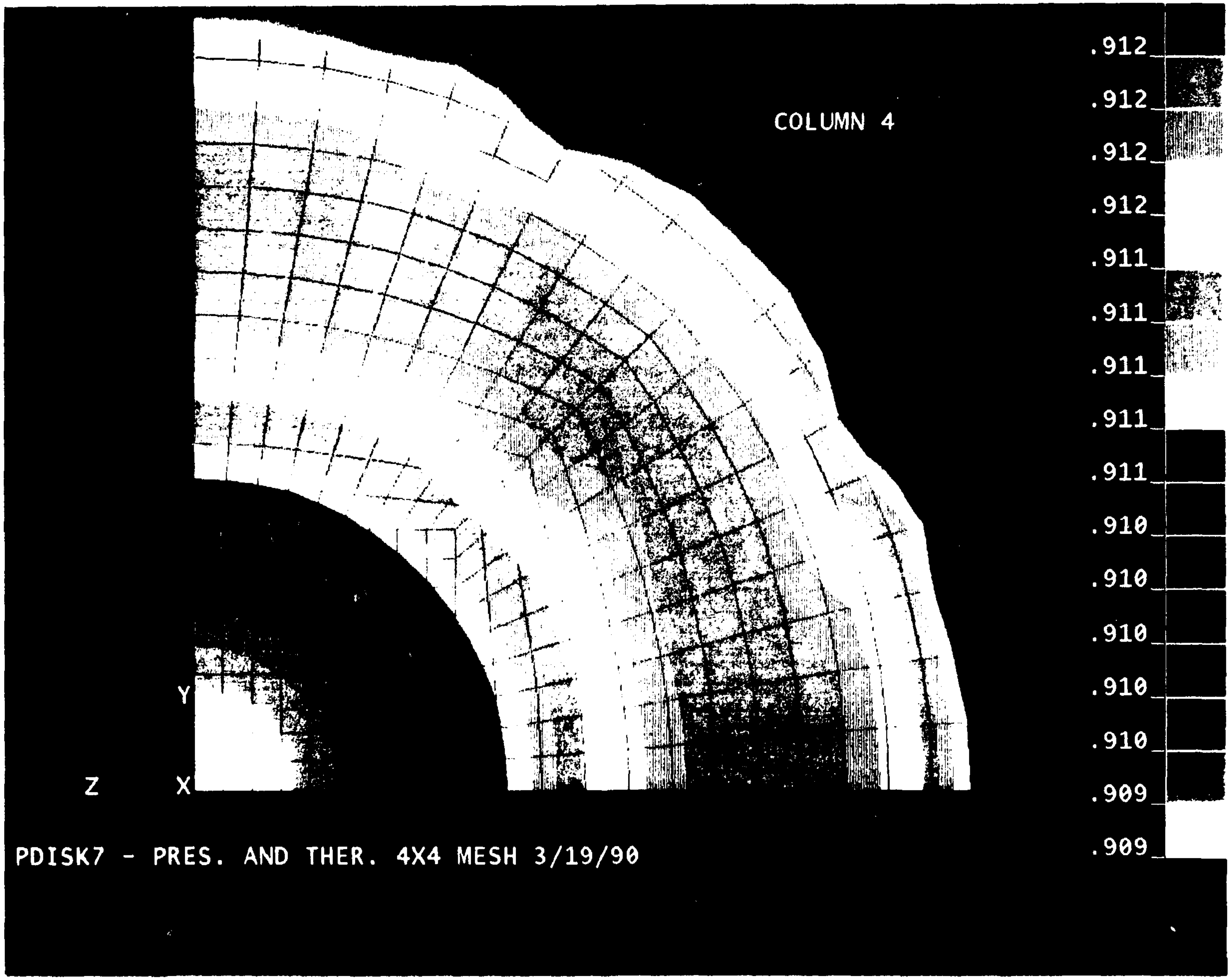

Figure [illegible].9. PATRAN Nodal Results (Column 4 Transmittance) for PDISK7 Example

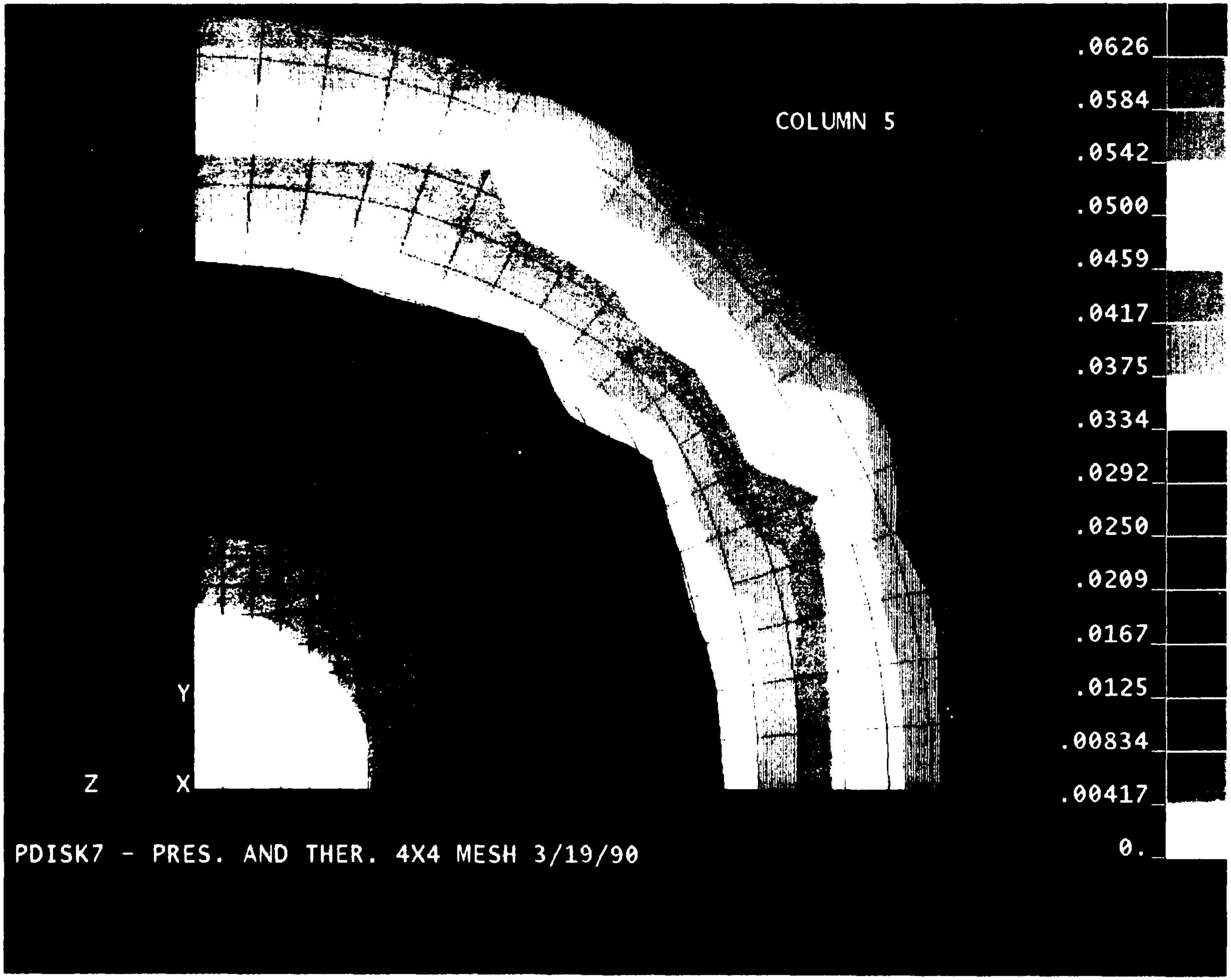

Figure 4.16 PATRAN Nodal Results (Column 5 Fraction Polarized) for PDISK7 Example

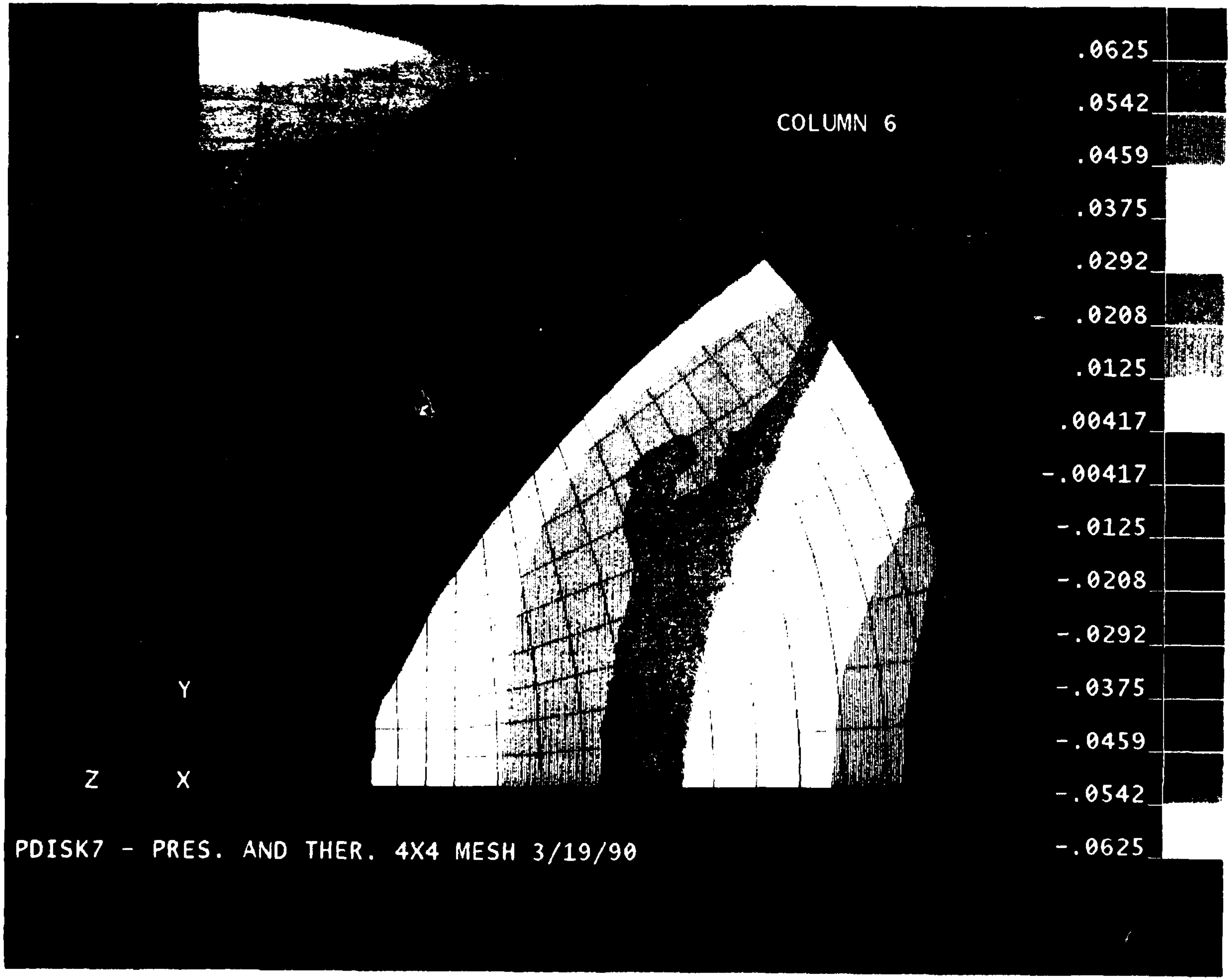

Figure 4.11. PATRAN Nodal Results (Column 6 Stokes S1) for PDISK7 Example

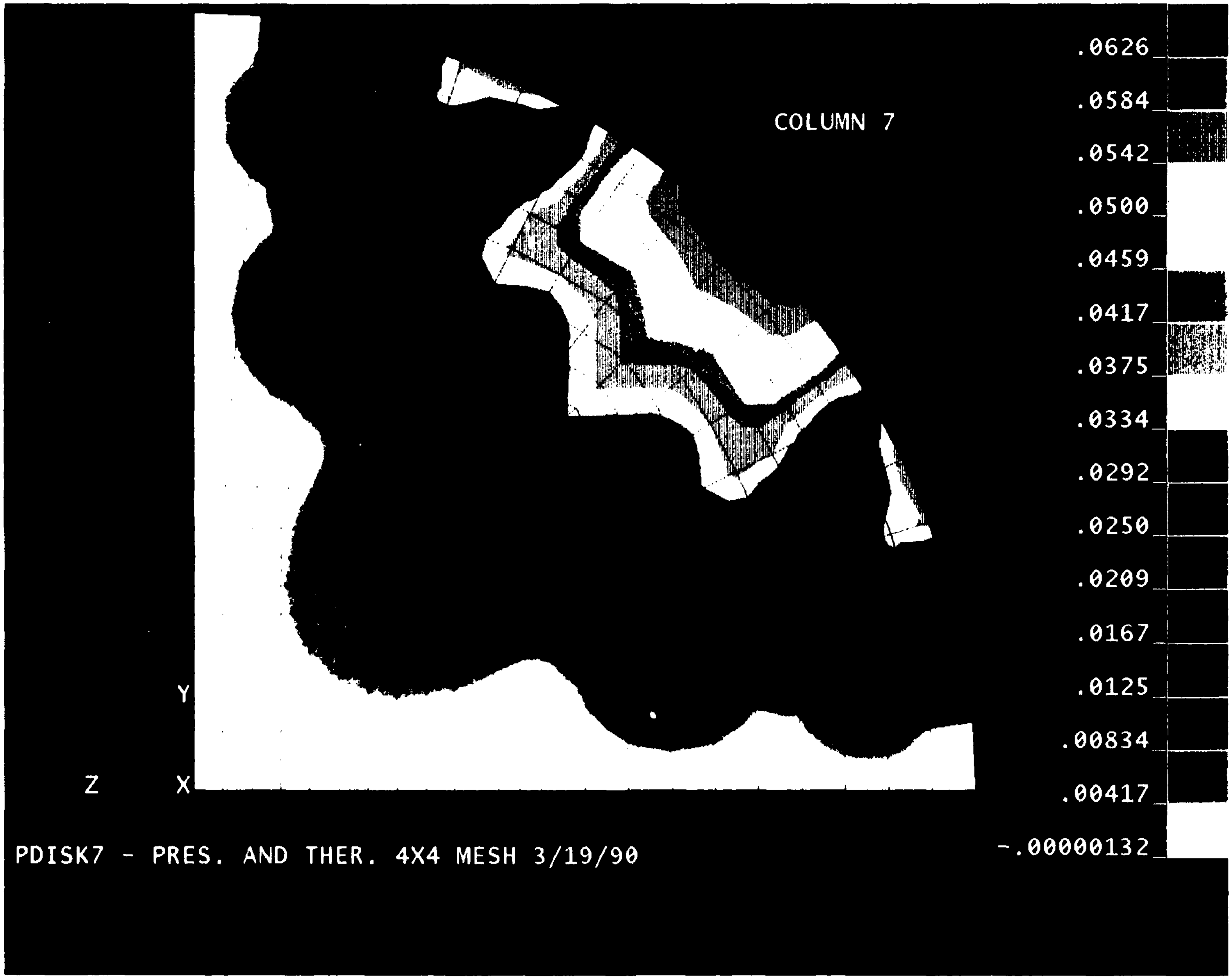

Figure 4.12. PATRAN Nodal Results (Column 7 Stokes S2) for PDISK7 Example

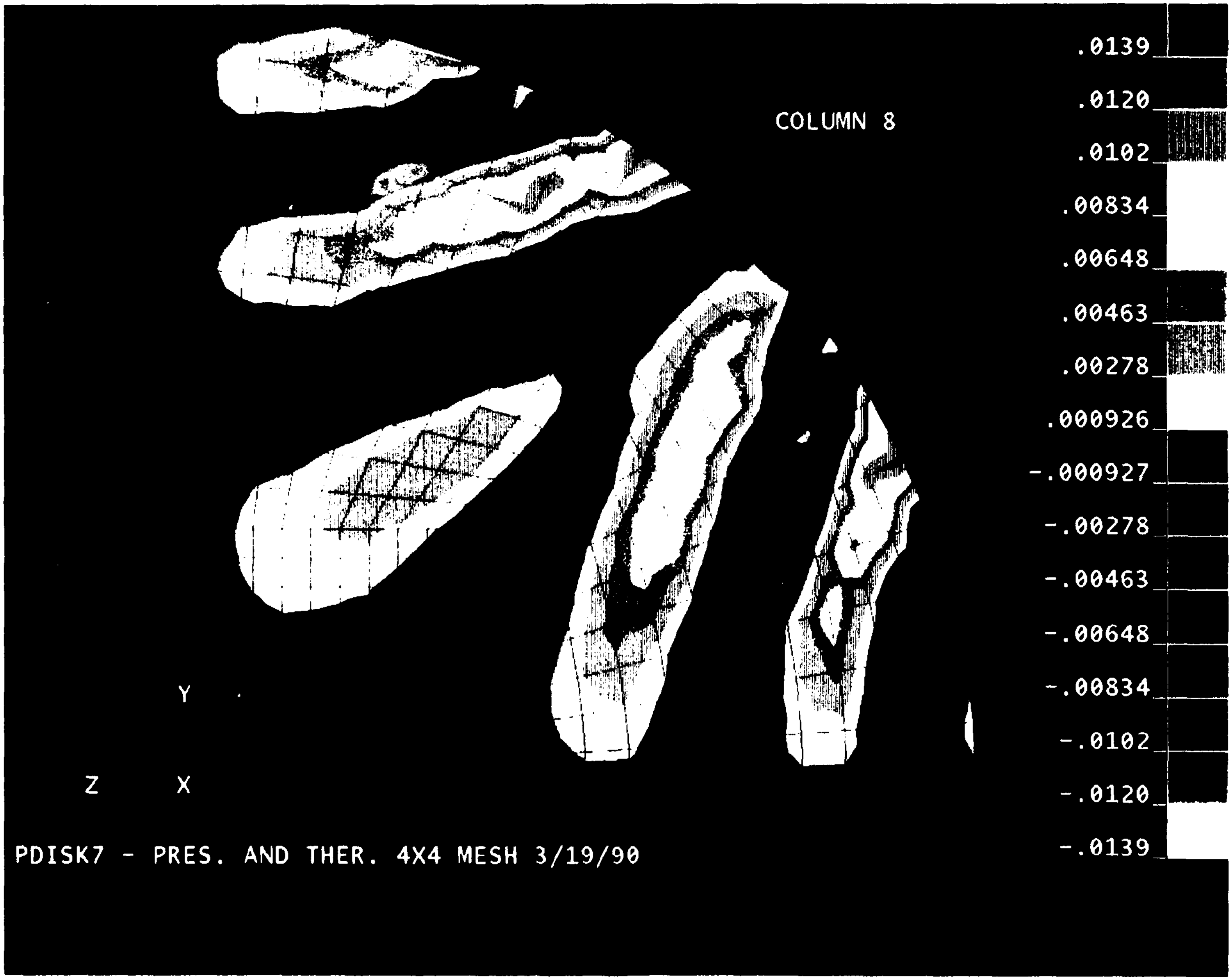

Figure 4.13. PATRAN Nodal Results (Column 8 Stokes S3) for PDISK7 Example

Essentially, the polarization effects are small and would have no effect on optical quality.

4.2 LOADED CANOPY WITH HUD AND VISOR EXAMPLE

Figure 4.14 is a shaded image of the undeformed canopy, HUD, and visor. The canopy is loaded by an internal pressure of 15 psi and a temperature gradient that varies from the leading edge and through the thickness. No loads are imposed on the HUD nor on the visor. Figure 4.15 shows finite element model used for the stress analysis. Figure 4.16 shows the canopy deformed geometry Geometric Hyperpatches generated by MAGOPT. Figure 4.17 shows the nodal and element mesh created by PATRAN post-processing of the OPOST file computed by MAGOPT. The MAGNA and MAGOPT CRAY/COS execution job file is shown in Table 3.2. Table 3.6 shows the VAX/VMS DCL CANOPY example OPTRAN execution command procedure. Table 4.4 below gives the material properties for the stress analysis. Material 1 is the outer layer of canopy, material 2 the canopy middle layer, and material 3 the canopy inner layer. The visor is material 4 and the HUD is material 5.

TABLE 4.4

CANOPY EXAMPLE MATERIAL PROPERTIES

MATERIAL	1	2	3	4	5
Young's Modulus (psi)	723900	355000	450000	355000	723000
Poisson's Ratio	0.17	0.37	0.35	0.37	0.17
Coefficient of Thermal Expansion	.00001	.00002	.00003	.00002	.00001

The canopy is loaded with an internal pressure of 15 psi and has a temperature gradient that varies from the leading edge to the trailing edge. The temperature on the inner surface at the leading edge is 100 degrees and varies quadratically as a function of distance from the leading edge. Temperature is 0 degrees on the inner surface at the trailing edge. There is also

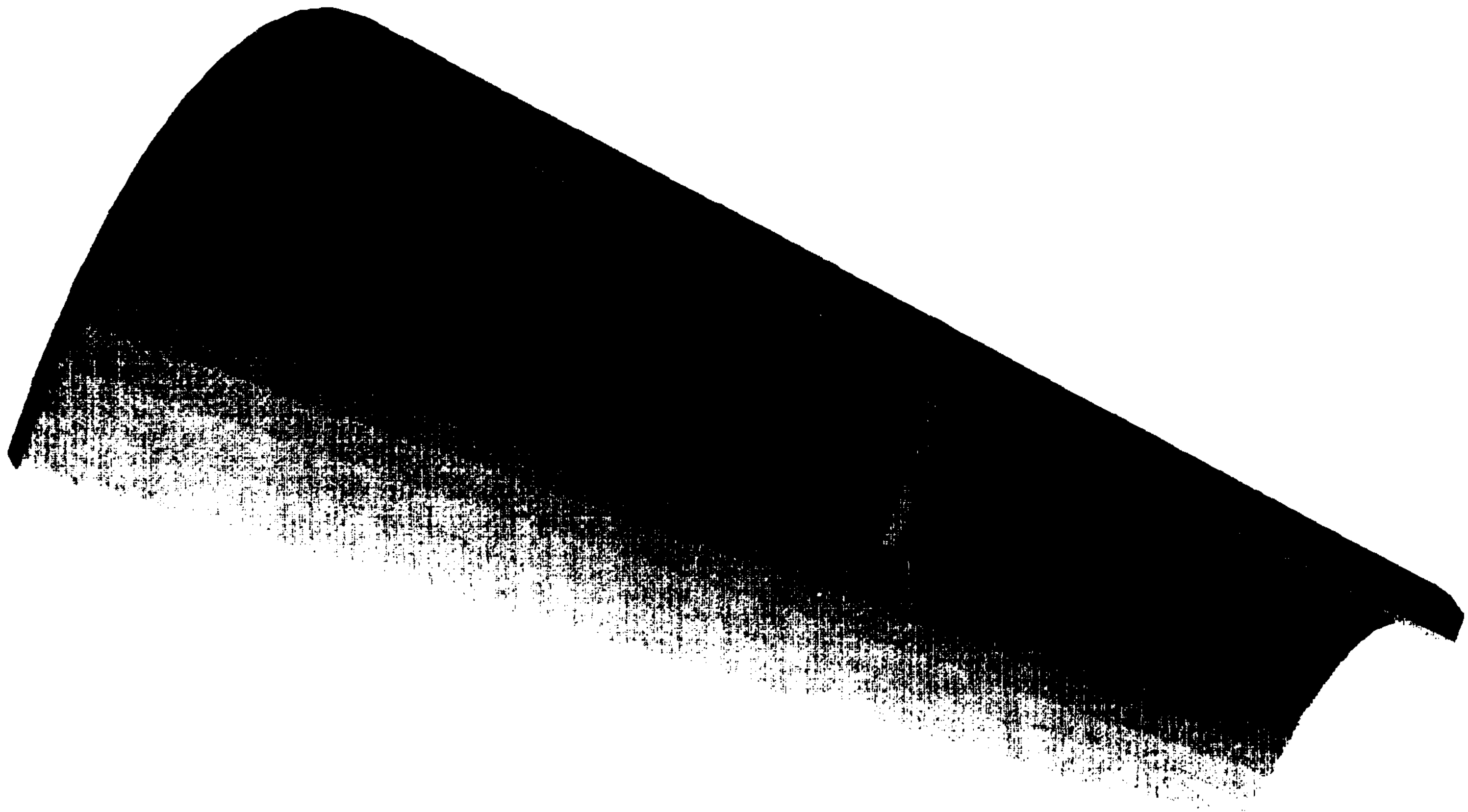

Figure 4.14. Canopy, HUD, and Visor Configuration

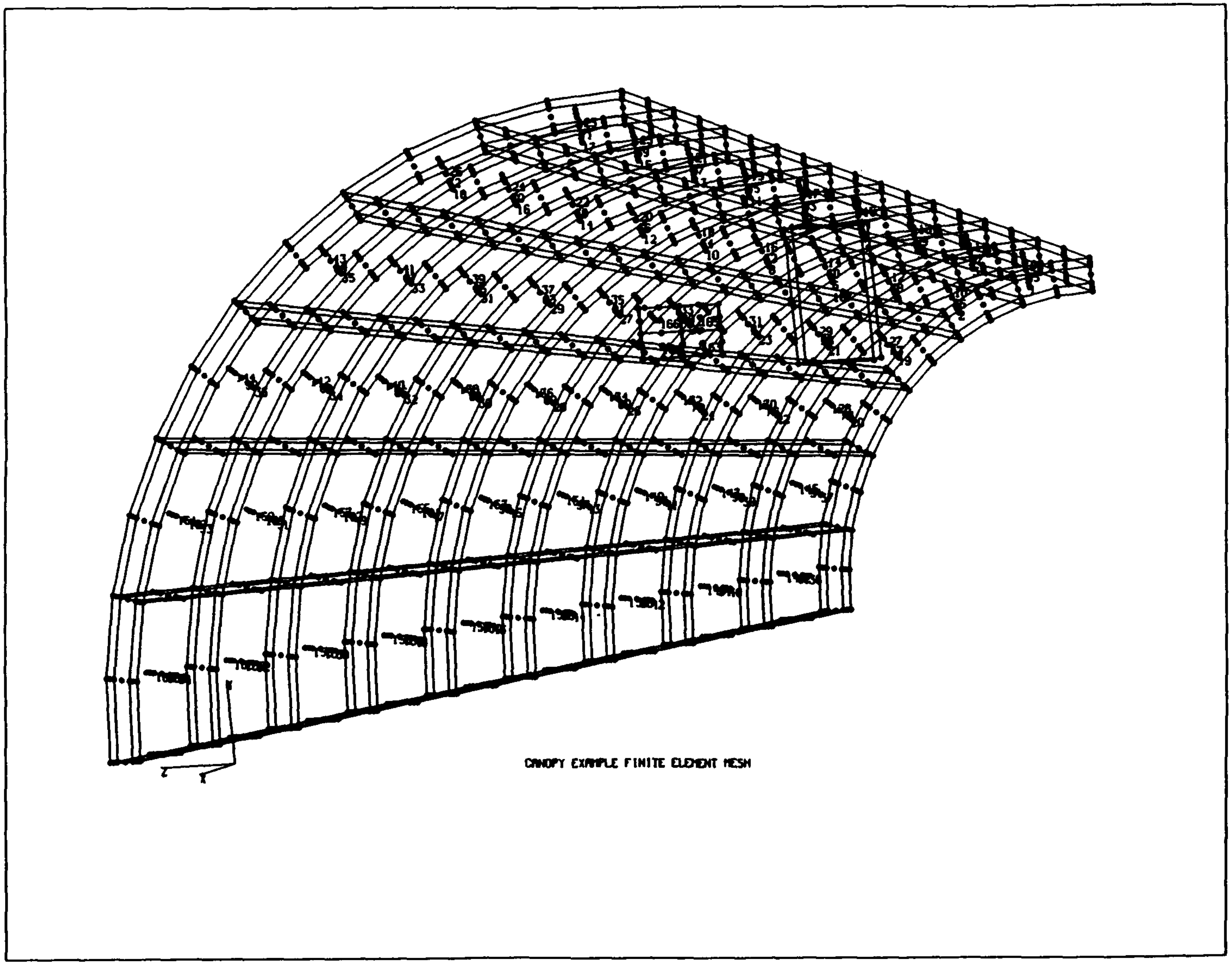

Figure 4.15. Canopy, HUD, and Visor Stress Analysis Finite Element Model.

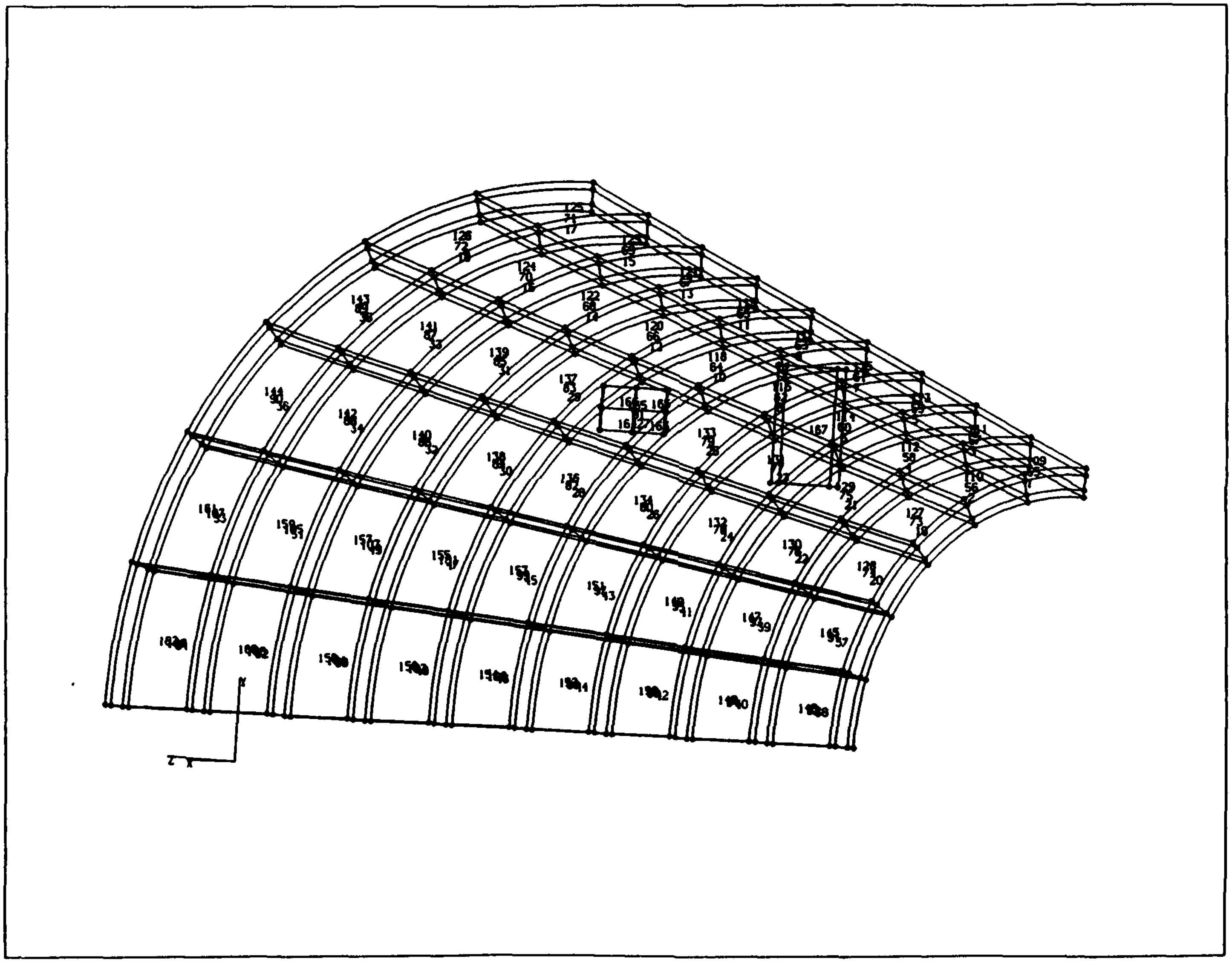

Figure 4.16. Canopy, HUD, and Visor Deformed Geometry Geometric Hyperpatches.

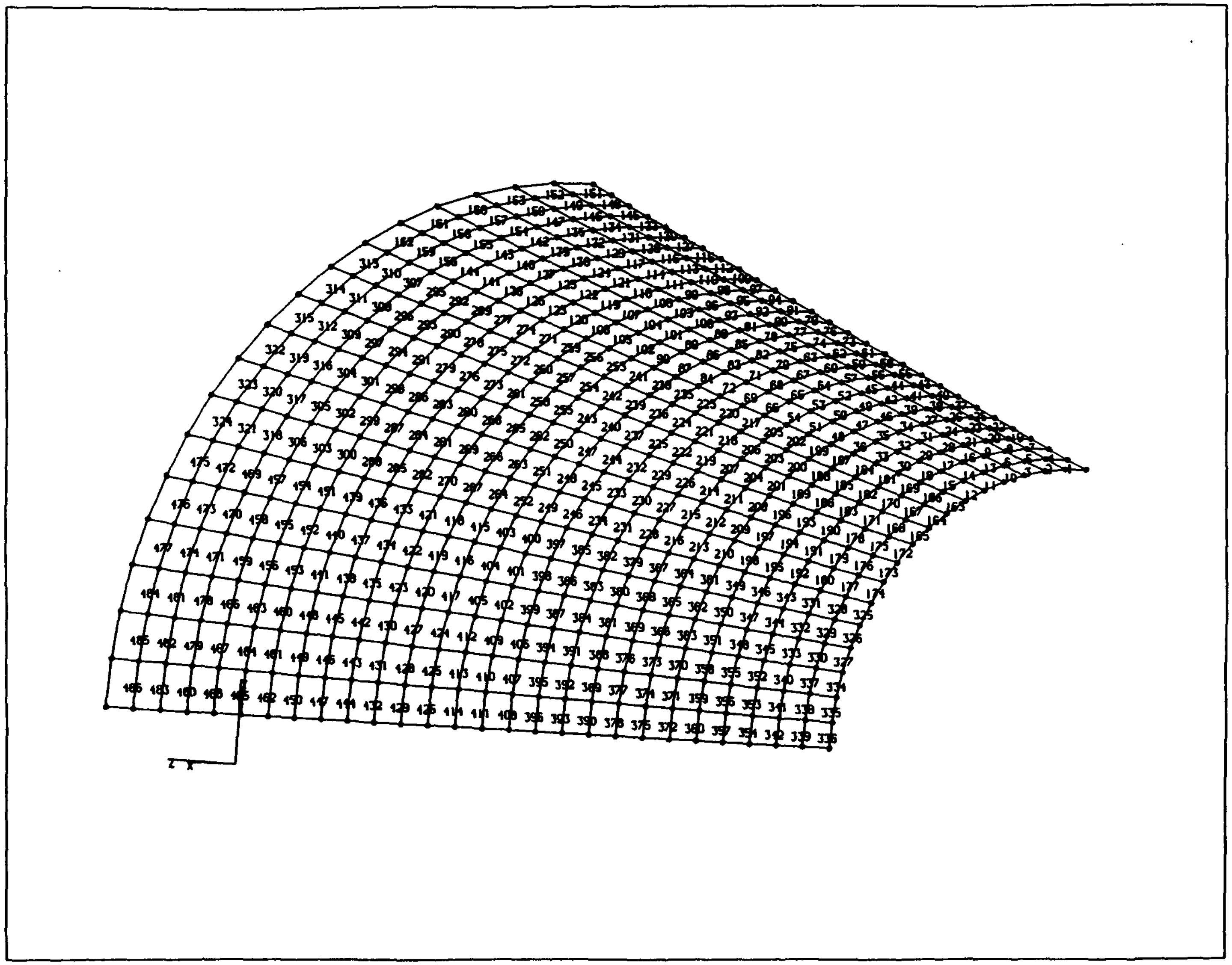

Figure 4.17. Canopy OPOST File Nodal and Element Mesh.

a linear 70 degree temperature variation through the thickness of the canopy. The outer surface is 70 degrees cooler than the inner surface. The following formula was used to compute temperature:

$$T = 100(\ 1 - X^2/60^2) - 70dt$$

where T is temperature, X is the distance from the leading edge, and dt is the percentage of the way through the thickness.

One purpose of this example is to illustrate a situation with multiple components. The OPTRAN input data file contents for this example are shown in Table 4.5. There are three components (parts) and for this example; the second two were assumed to be bypassable. Another purpose was to test extremes in field of view, which extends well over 90 degrees to the left of the eye position. This is a nontrivial exercise as was discovered during code development.

Figure 4.18 shows the grid distortion over a rectangular area within the "visor" area and slightly overlapping the HUD. The distortion is readily apparent, especially near the bottom of the grid. The amount of distortion would probably be judged acceptable. Figure 4.19 shows the angular deviation (at normal scale), and Figure 4.20 shows the same data at a scale of 10. Figures 4.21 through 4.23 show the magnitude and components of angular deviation over the entire canopy. Discontinuities can be observed marking the projected boundary of the "visor," but no other feature can be readily explained.

Figure 4.24 shows the transmittance, which is high for light that only passes through the canopy, less for light that passes through the canopy and visor, and lowest for light passing through all three components. Figure 4.25 shows the polarization effects, which are larger than for the disk example, with areas showing as large as 0.20 of the incident light being polarized. The Stokes parameters, shown in Figures 4.26 through 4.29, show complicated variations, but the total visual effect is small since the eye is relatively insensitive to polarization.

TABLE 4.5

OPTRAN CANOPY INPUT DATA CONTROL RECORD

```
C Cockpit simulation
EYE    51.0  22.5   1.5
VIEW
   X   0.0   0.0  -1.0
   Y   0.0   1.0   0.0
   Z   1.0   0.0   0.0
MEDIA
     1  109   162
     2   55   108
     3    1    54
     4  163   166
     5  167

SURFACE
     1    1    6  109  162
     3    2    5    1   54
     4    3    6  163  166
     4    4    5  163  166
     5    5    1  167
     5    6    2  167

PARTS
     1    1    2    0
     2    5    6    1
     3    3    4    1

MPROP
     1       1.51    2E-4     1E-9        2E-10
     2       1.62   -6E-5    -2E-9        5E-11
     3       1.48    3E-5     3E-9       -8E-10
     4       1.50
     5       1.52

RESULTS
AXES -120 20 20 -40 100 20
OUTLINE
GRID -60 0 10 -20 40 10
END
```

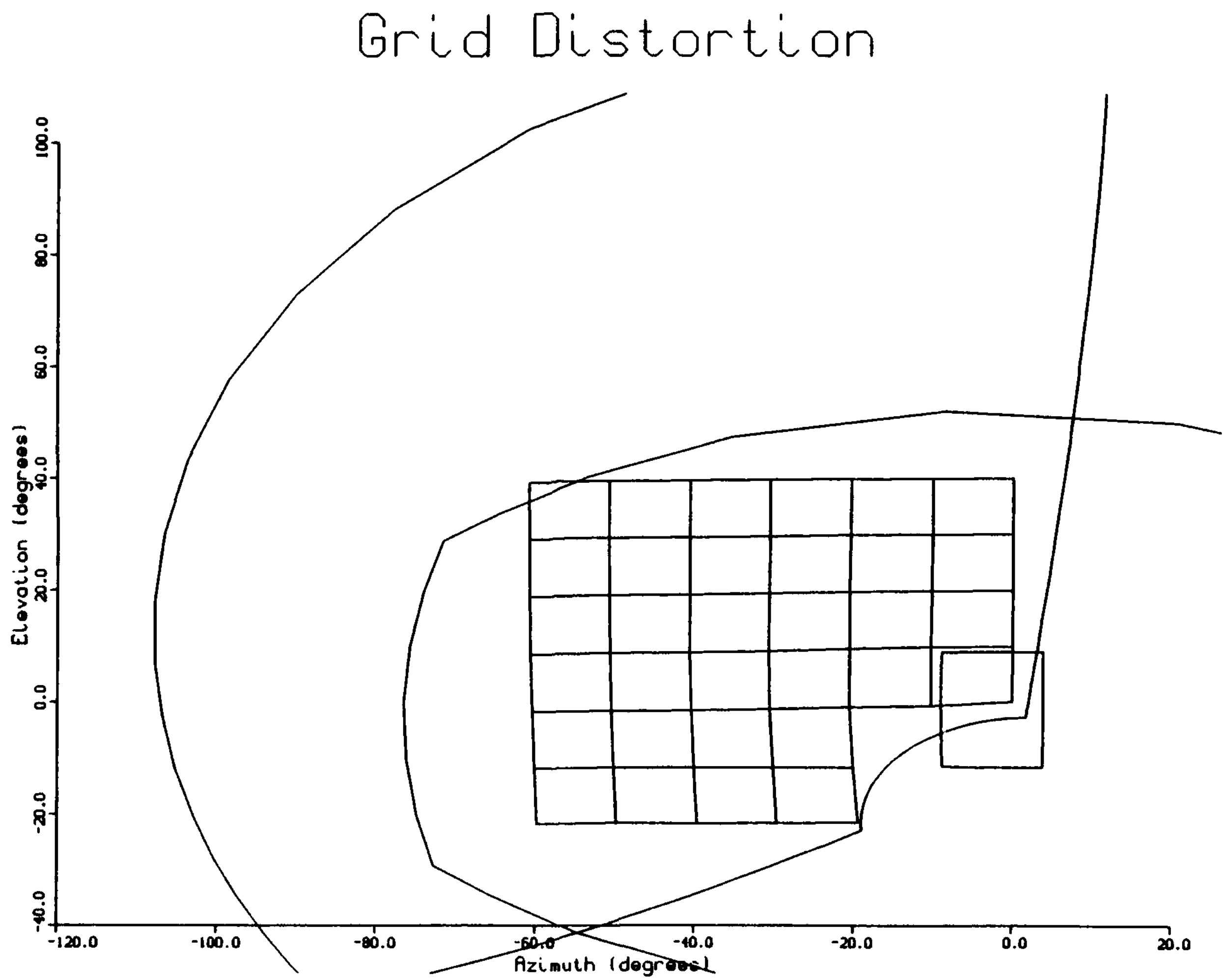

Figure 4.18. Grid Distortion vs. Angle for CANOPY Example.

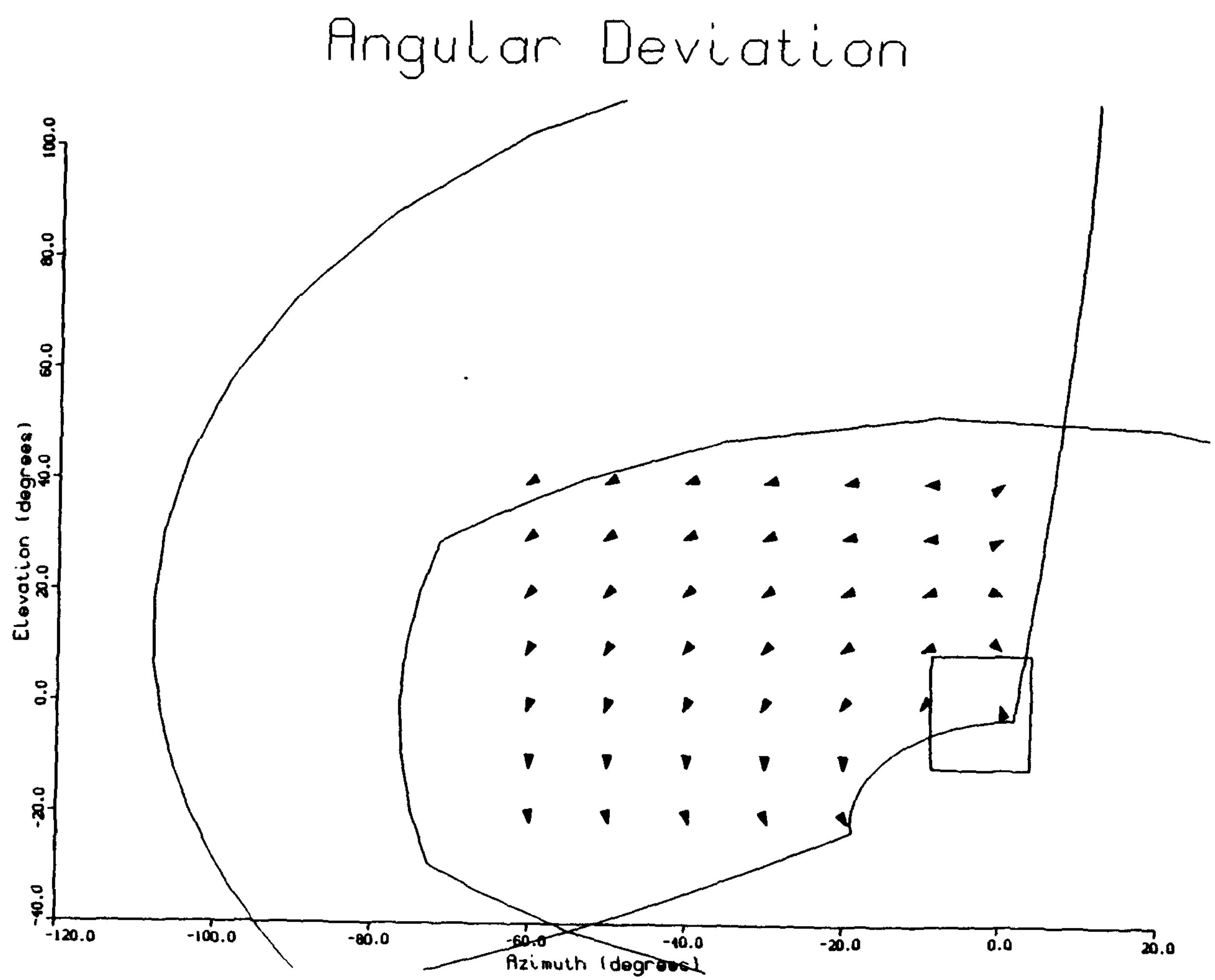

Figure 4.19. Angular Deviation (normal scale) vs. Angle for CANOPY Example.

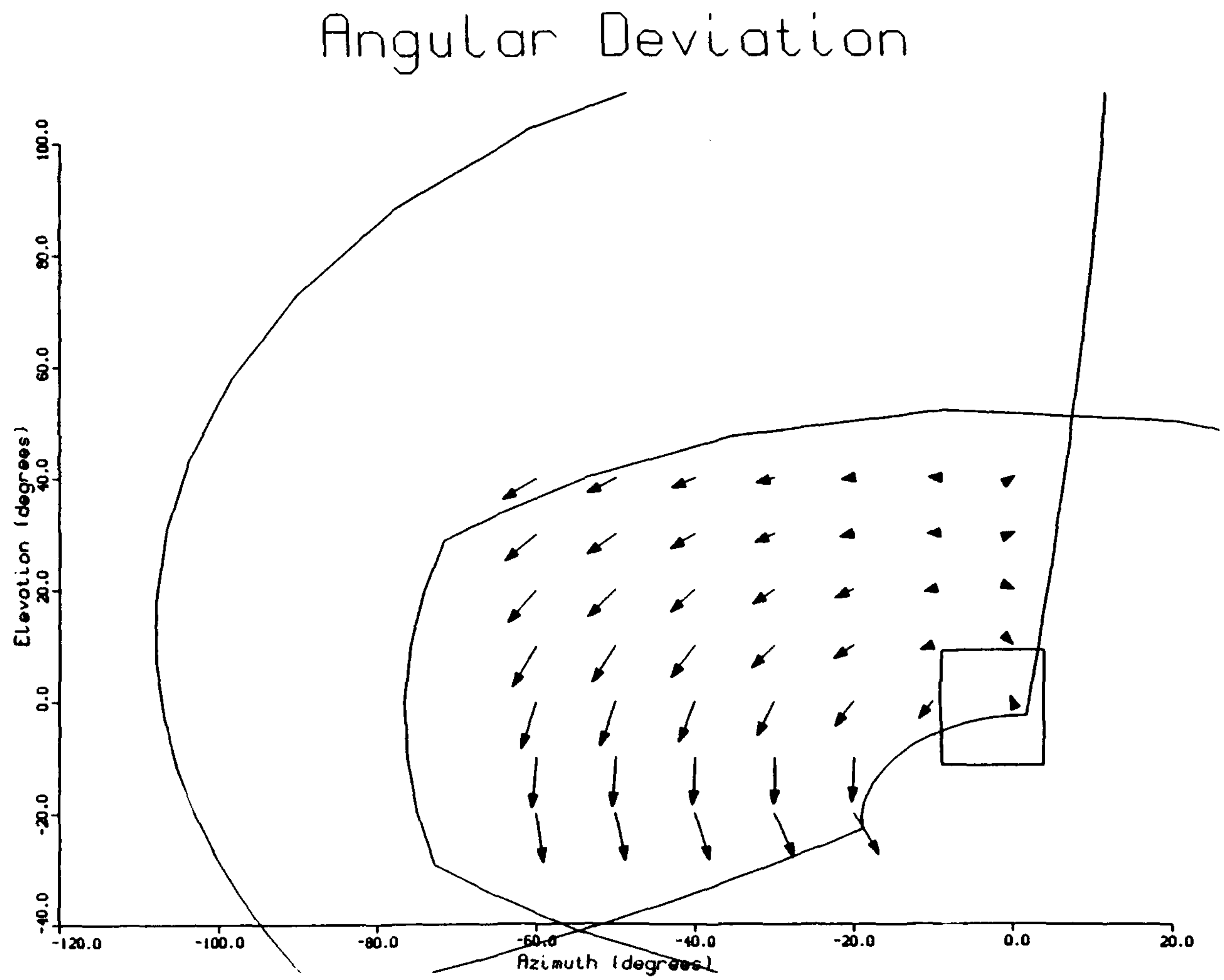

Figure 4.20. Angular Deviation (magnified) vs. Angle for CANOPY Example.

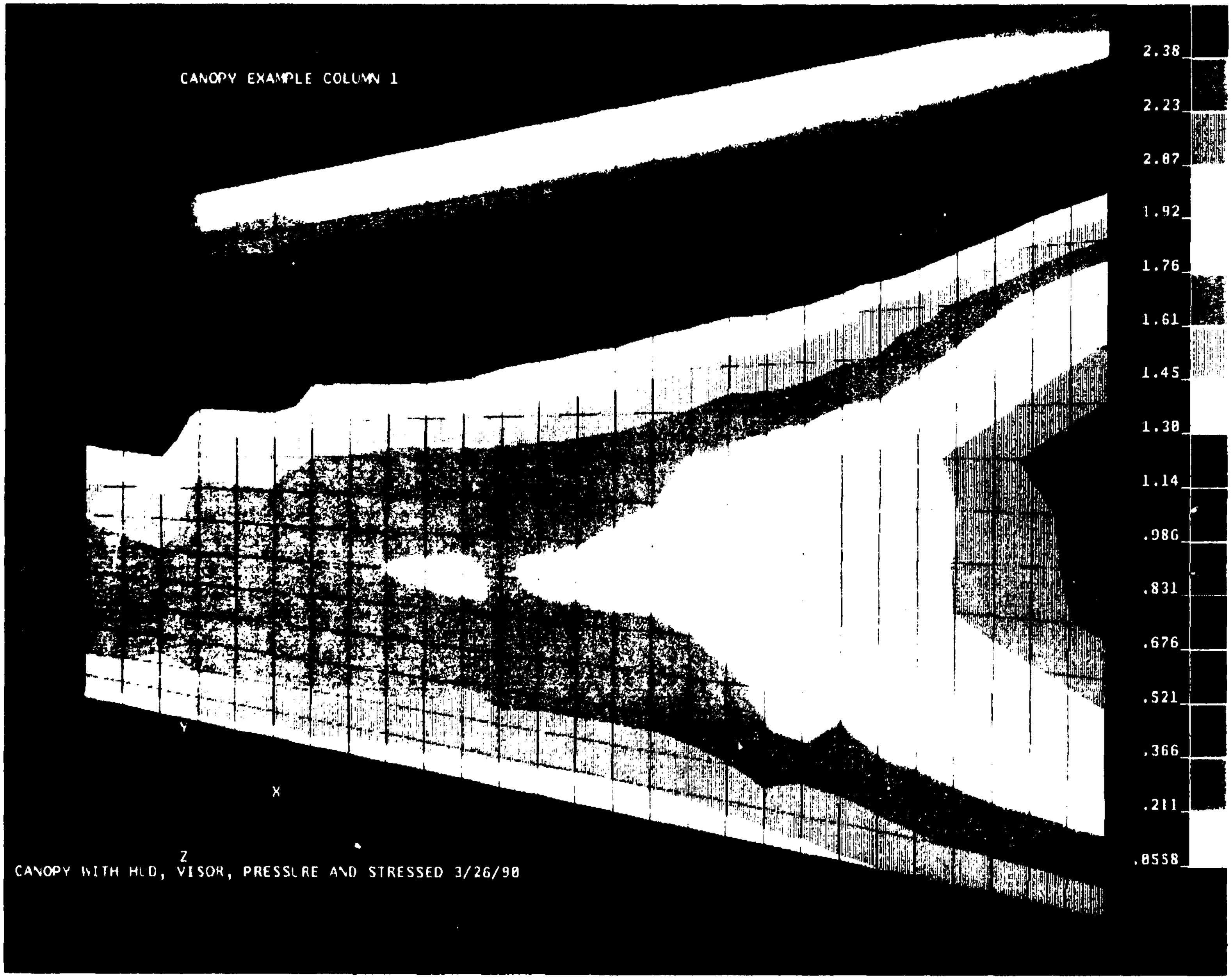

Figure 4.21. PATRAN Nodal Results (Column 1 Angular Deviation) for CANOPY Example

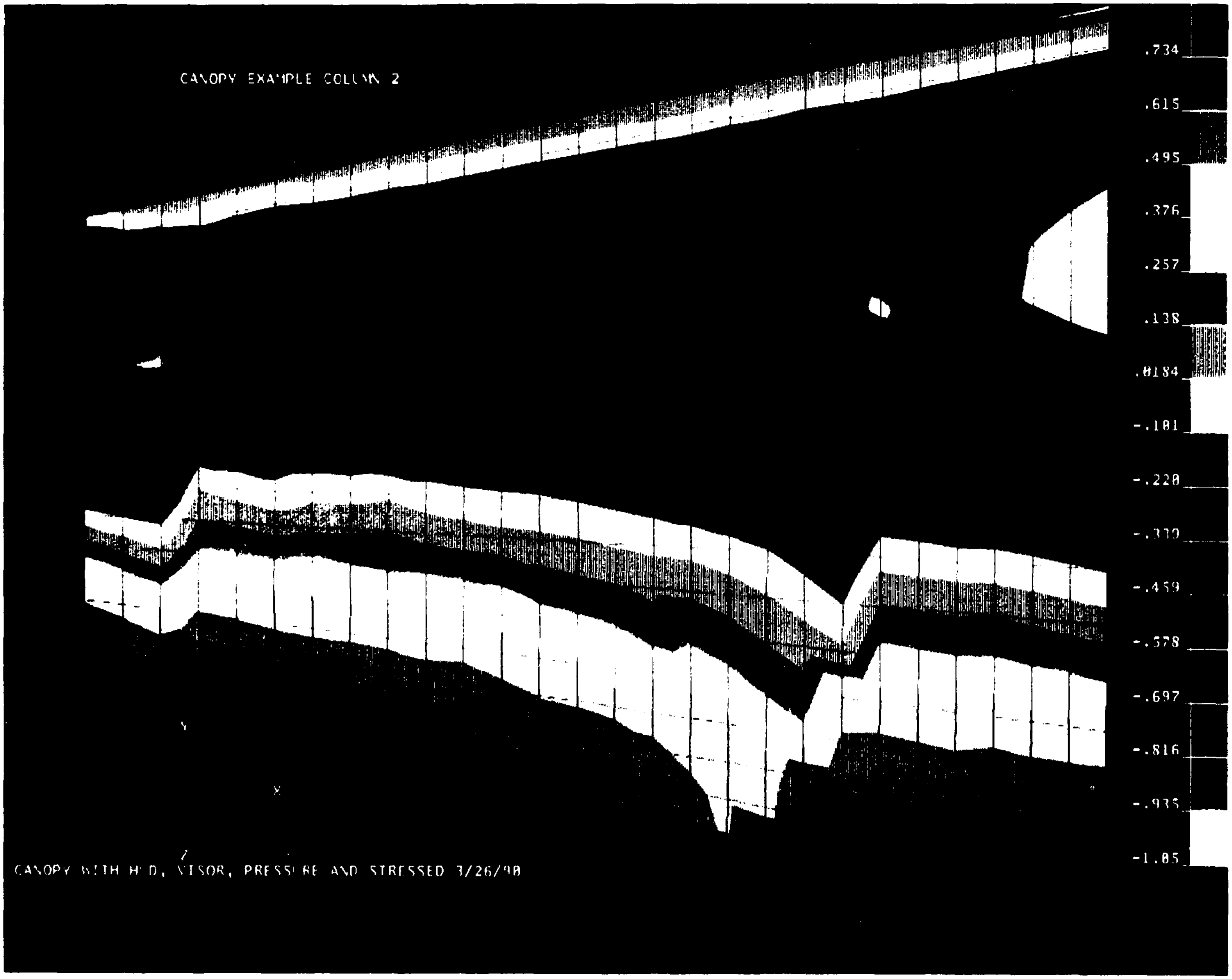

Figure 4.22. PATRAN Nodal Results (Column 2 Azimuthal Component of Angular Deviation) for CANOPY Example

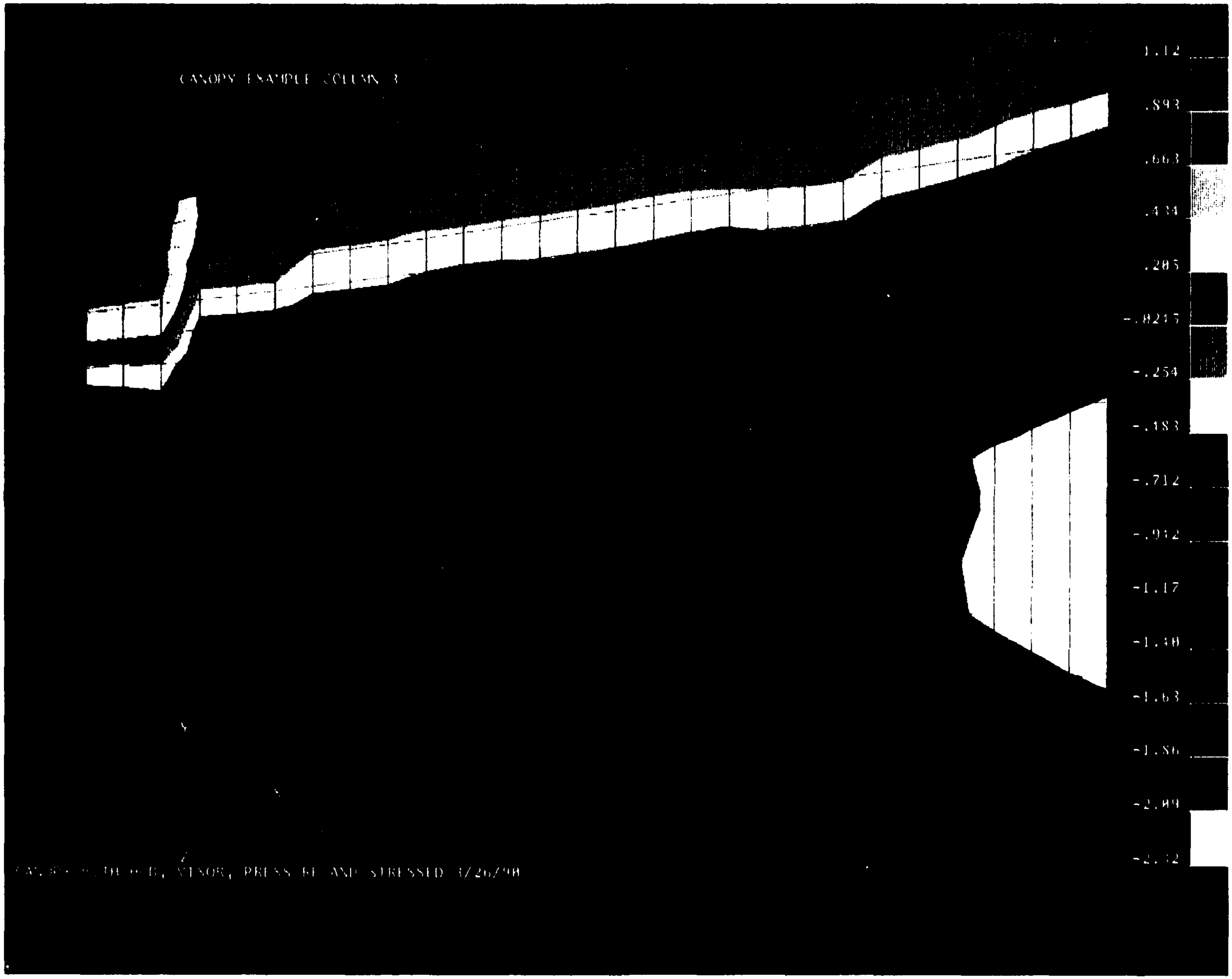

Figure 4.23. PATRAN Nodal Results (Column 3 Elevation Component of Angular Deviation) for CANOPY Example

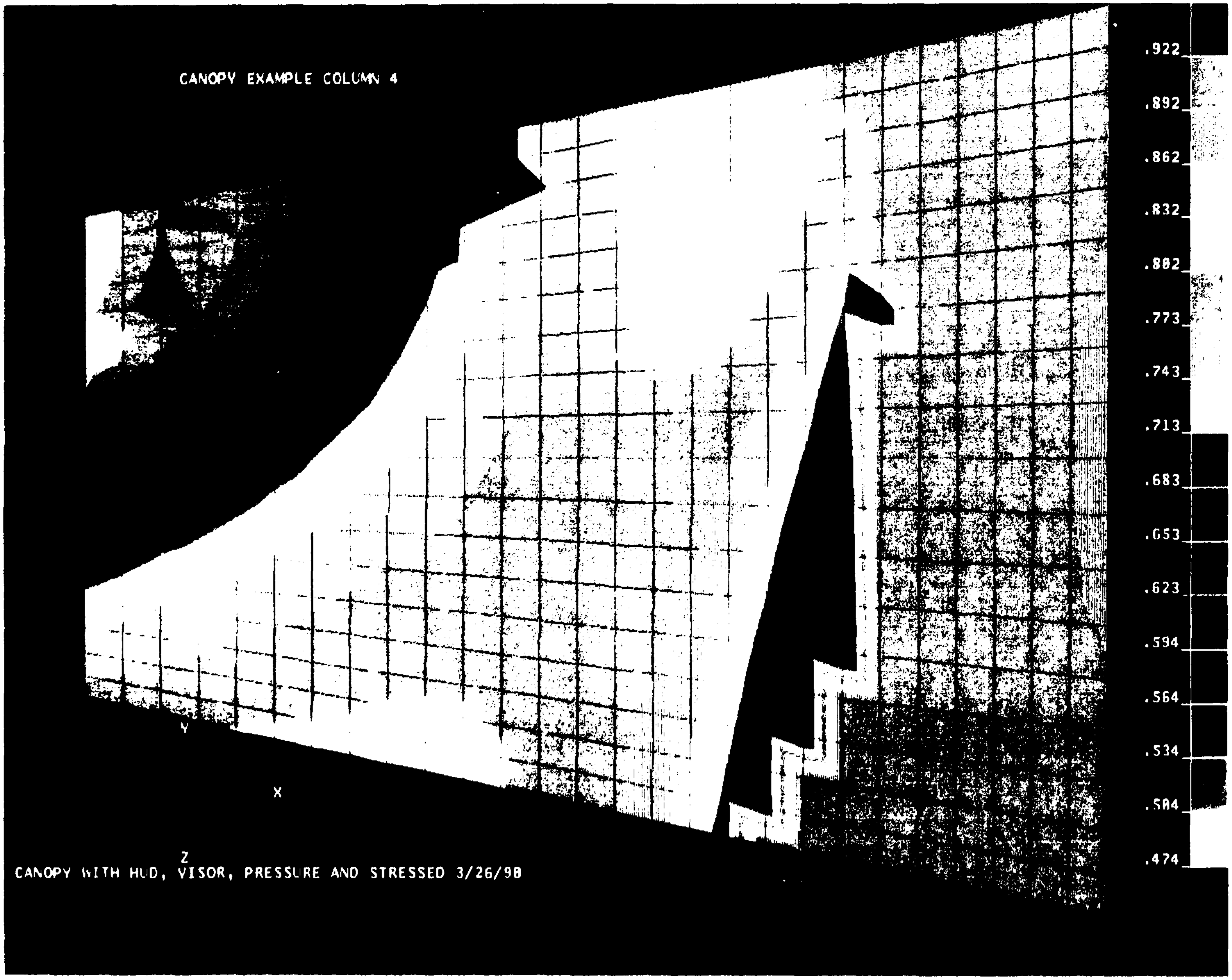

Figure 4.24. PATRAN Nodal Results (Column 4 Transmittance) for CANOPY Example

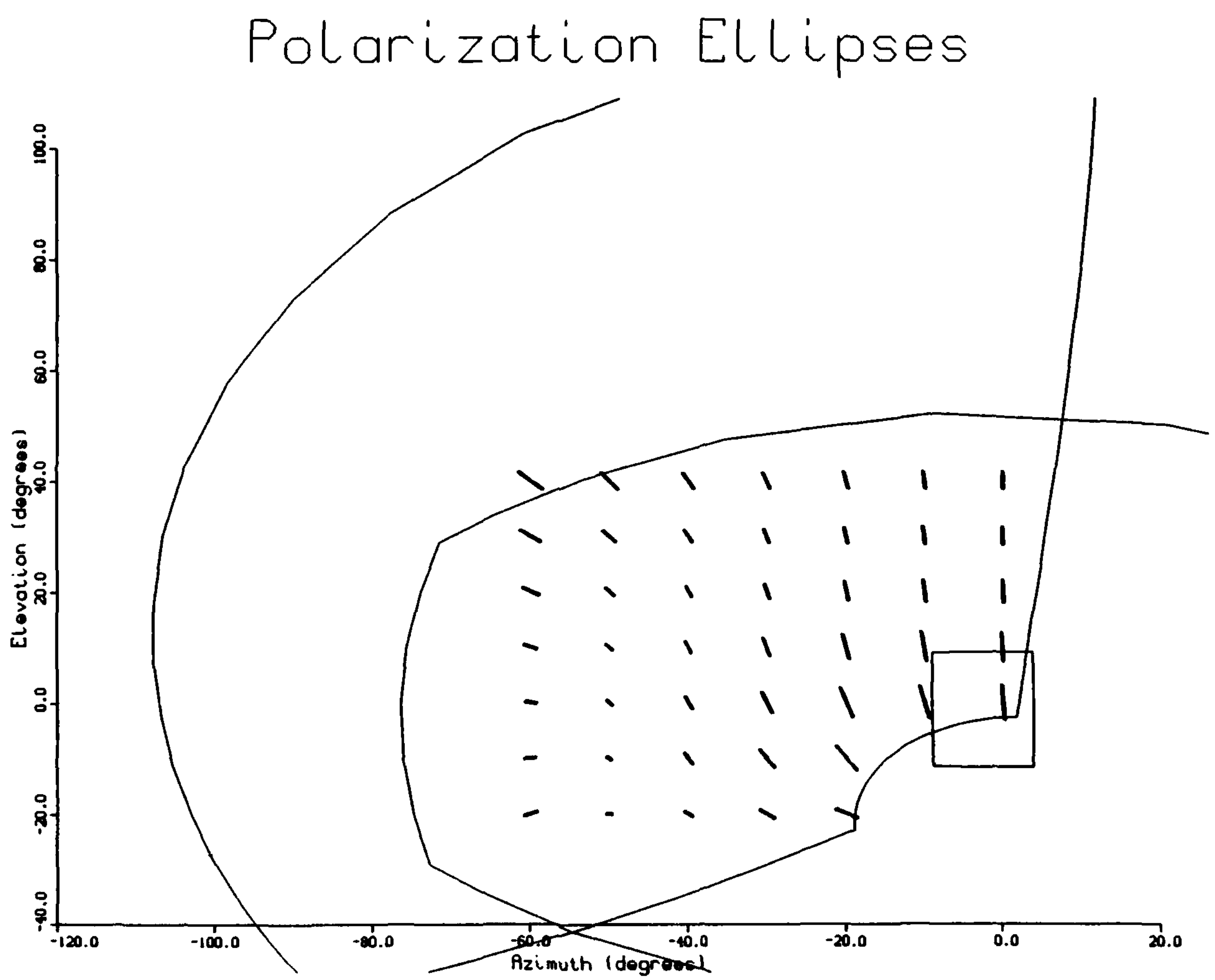

Figure 4.25. Polarization vs. Angle for CANOPY Example.

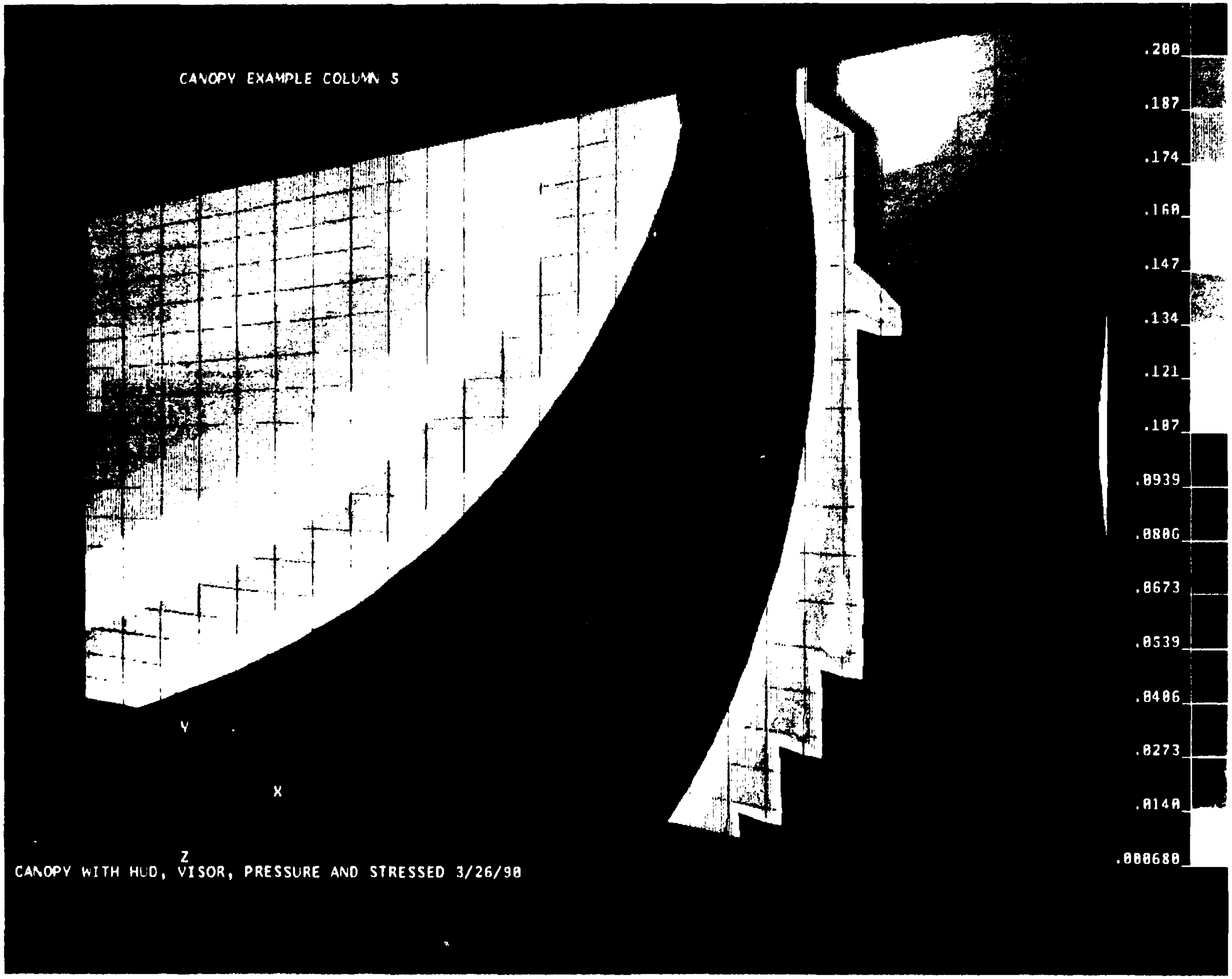

Figure ..26. PATRAN Nodal Results (Column 5 Fraction Polarized) for CANOPY Example

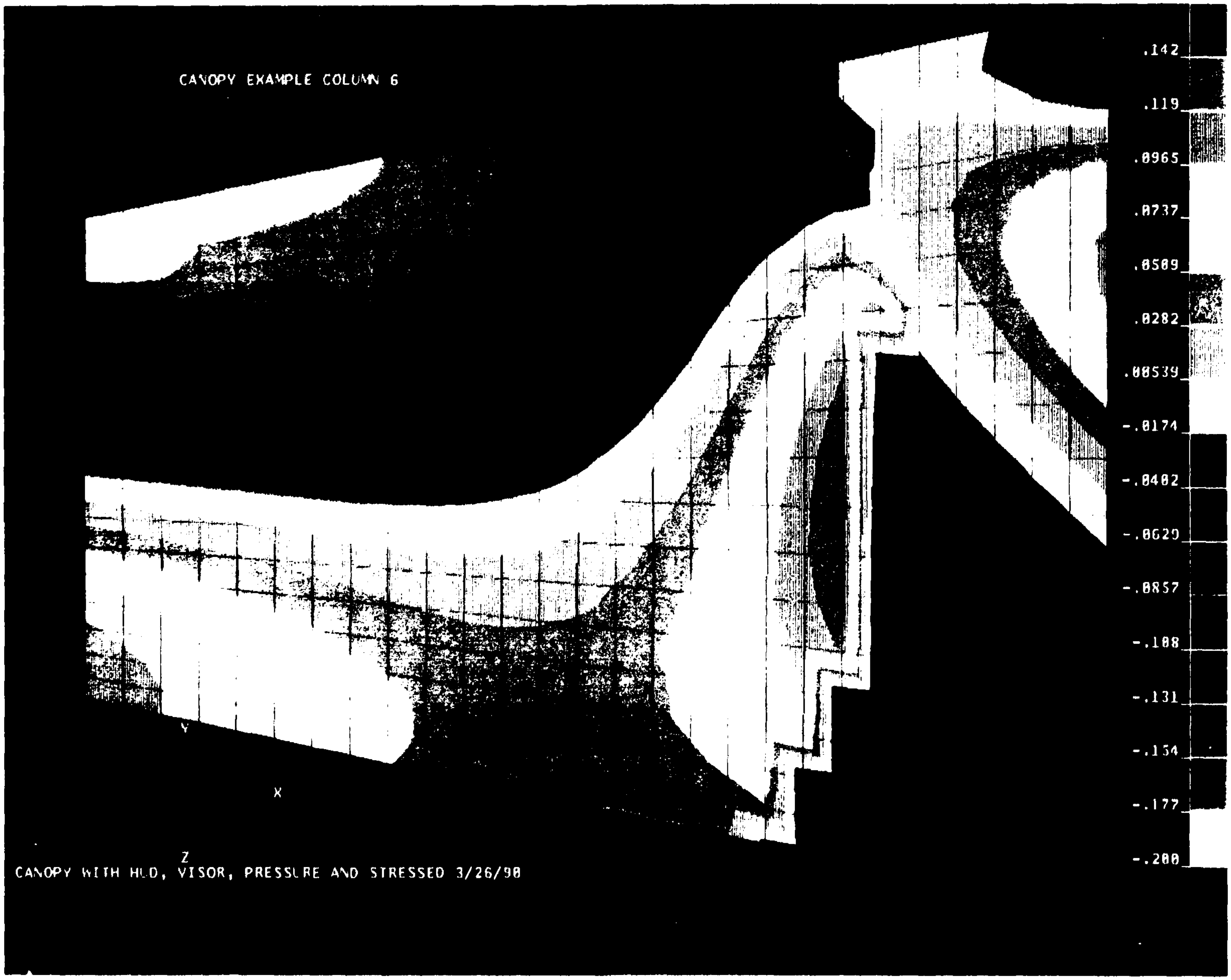

Figure 4.27. PATRAN Nodal Results (Column 6 Stokes S1) for CANOPY Example

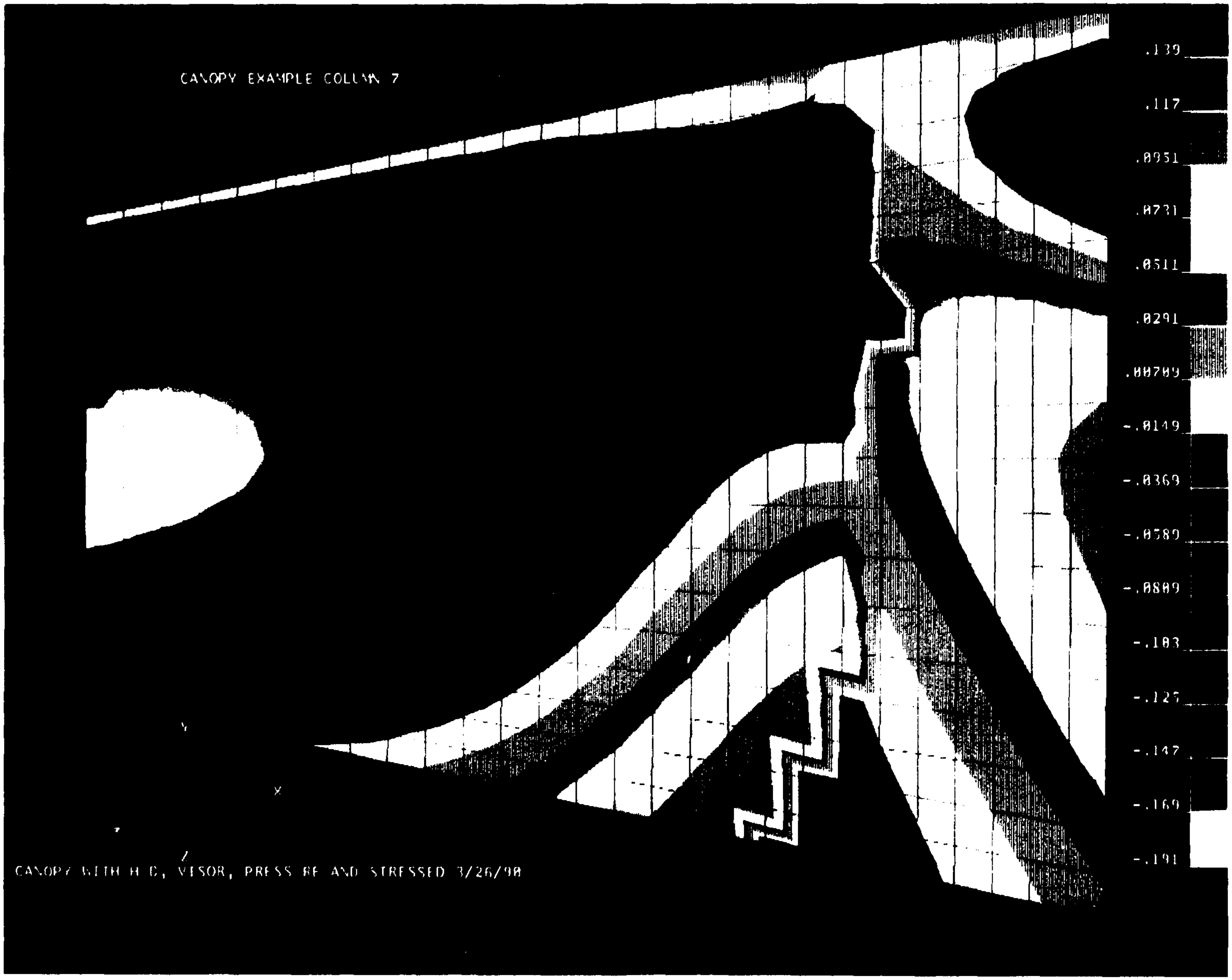

Figure 4.28. PATRAN Nodal Results (Column 7 Stokes S2) for CANOPY Example

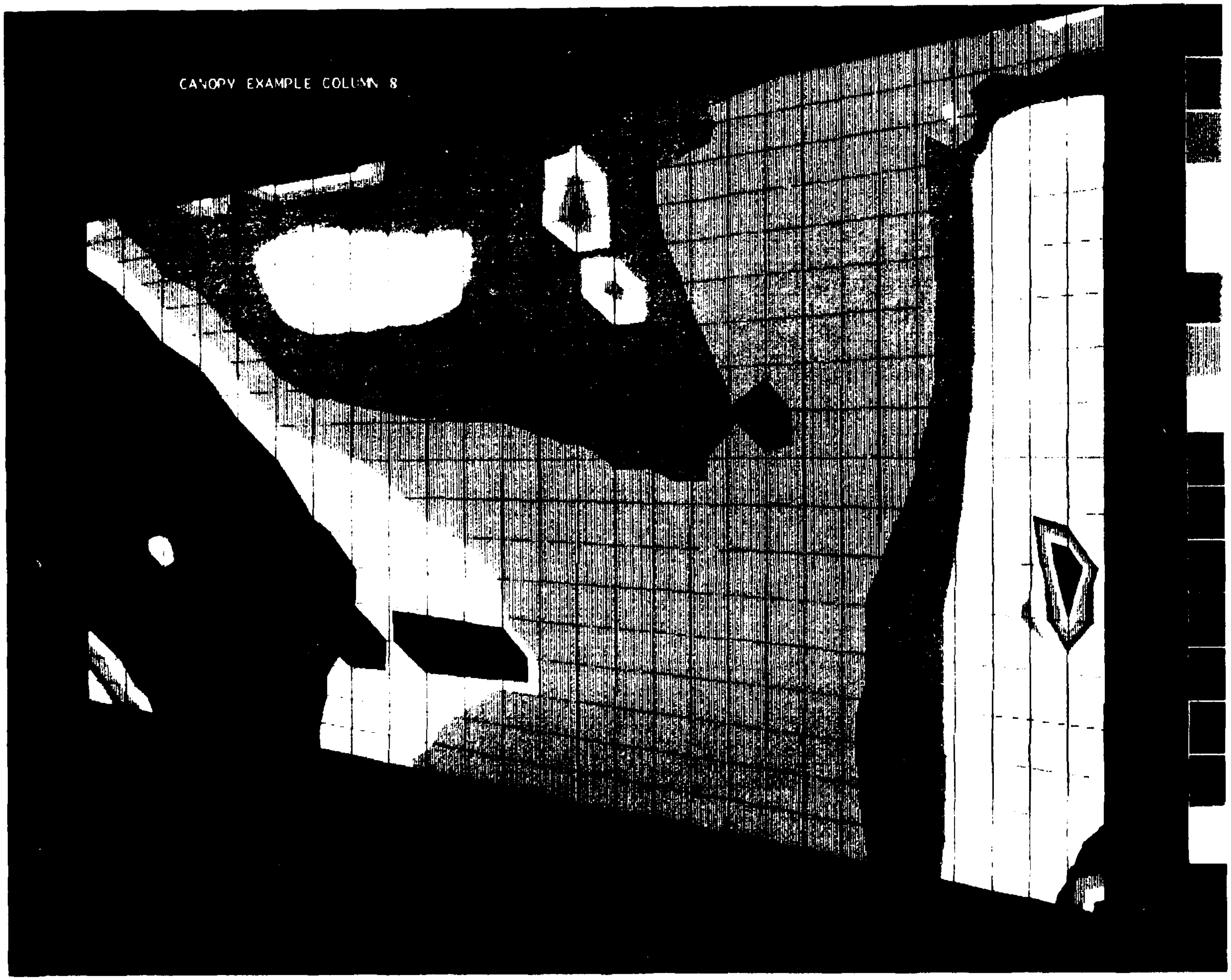

Figure 4.29. PATRAN Nodal Results (Column 8 Stokes S3) for CANOPY Example

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